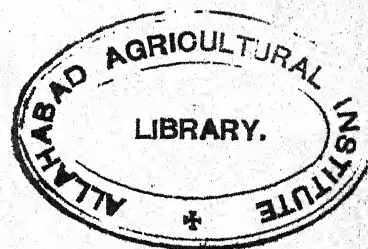


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Volume IV



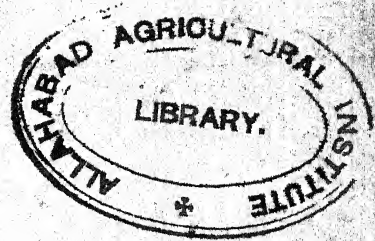
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THE GASES OF SWAMP RICE SOILS.

PART II.

THEIR UTILIZATION FOR THE AERATION OF THE ROOTS OF THE CROP.

BY

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INTRODUCTORY.

IN a recently published paper¹ dealing with the gases of Swamp Rice Soils, we showed that the gases formed in the soil appeared to have an important connection with the aeration of the roots of the crop.

The chief facts which led us to this conclusion may be briefly stated as follows:—

1. The gases which occur in the soil consist mainly of methane and nitrogen, together with small amounts of carbon-dioxide and hydrogen, and these, with the exception of nitrogen, may be looked upon as the characteristic soil gases.²

¹ Harrison and Subramania. "The Gases of Swamp Rice Soils," *Mem. Dept. Agri. India, Chem. Ser.*, Vol. III, No. 3.

² *Ibid*, p. 68.

2. The surface of the soil immediately in contact with the irrigation water is covered by an organized film which evolves considerable quantities of gas, of which oxygen is one of the chief constituents and which is utilized for the aeration of the roots of the rice crop. Further a careful examination of this gas thus evolved shows that it contains no trace of the characteristic soil gases, so long as the surface of the soil is not disturbed, and it must therefore be concluded, that either the production of methane, etc., in the soil is not sufficiently large to cause it to be discharged through the surface of the soil, or that the organized film possesses the power of arresting and assimilating these gases.¹

3. That the first supposition is incorrect is demonstrated by the fact that when the growth of the film is prevented, *e.g.*, by the use of copper sulphate in the irrigation water, the characteristic soil gases escape from the soil in abundance and can easily be collected.²

4. That the second hypothesis is probably correct is shown by the facts (a) that the addition of green manure to the soil greatly increases the production of methane;³ and (b) that this increased production of gas coincides with an increased evolution of oxygen from the surface film.⁴

Consequently it appeared very probable that the organisms forming the surface film possess the power of utilizing the characteristic soil gases so as to lead to an increased output of oxygen at the surface of the soil. This result might possibly be brought about by one, or both of two methods. Either the gases may be utilized directly in the metabolism of the organisms or they may be oxidized at the expense of the oxygen dissolved in the irrigation water, and

¹ Harrison and Subramania. "The Gases of Swamp Rice Soils," *Mem. Dep. Agri. India, Chem. Ser.*, Vol. III, No. 3, pp. 89—93.

² *Ibid.*, p. 77.

³ *Ibid.*, p. 79.

⁴ *Ibid.*, pp. 104-6.

the carbon-dioxide thus produced be in turn decomposed by the green algæ present in the film with the liberation of gaseous oxygen.

The first supposition does not appear to be very probable, because then the sole source of the evolved oxygen could only be the carbon-dioxide dissolved in the irrigation water and the action of green manures in increasing the output of oxygen would appear to be very obscure. On the other hand, the work of Söhngen,¹ Kaserer,² and others, on the bacterial oxidation of methane and hydrogen makes the second supposition appear very probable and would account at the same time for the effect of green-manuring.

In order to test these hypotheses a series of experiments were initiated to determine the action of the film on the soil gases and the nature of the agents to which the changes produced could be ascribed. The results of this investigation are detailed in the following pages.

EXPERIMENTAL.

The Action of the Surface Film on the Soil Gases.

Several different types[†] of the surface film from Swamp Rice Soils were sealed up in glass vessels with a few cc. of a sterile mineral nutrient solution* and a known volume of a mixture of the soil gases. The usual method adopted in carrying out these experiments with the film was to take a cylindrical separating funnel A, the stopper of which is replaced by a rubber cork through which passed a capillary glass tap B and to which was sealed a small bulb C filled with cotton-wool. The cylinder was completely filled with mineral nutrient solution by suction at C and the tap B closed. The whole was then sterilized in the autoclave, the tap D

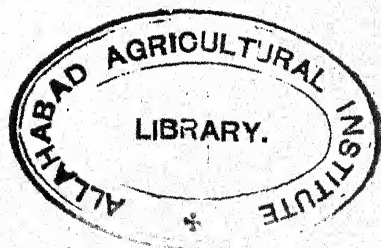
¹ Söhngen, *Centbl. Bakt.* 2 abt., 15 (1905), p. 573.

² Kaserer, *Centbl. Bakt.* 2 abt., 15 (1905), p. 573, 16 (1906), p. 681.

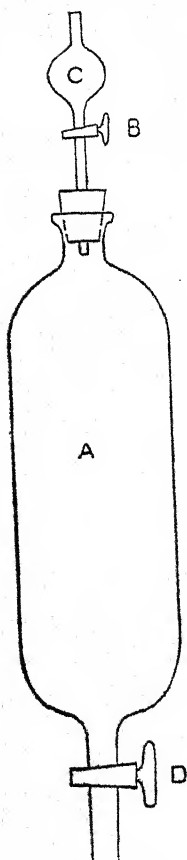
* *Note.*—In all these experiments Kaserer's (*loc. cit*) mineral solution was used consisting of—

K ₂ HP O ₄	0.05%
Mg SO ₄	0.02%
NH ₄ Cl	0.10%
NaHCO ₃	0.05%
Fe Cl ₃	trace.

Other solutions were tried, but the above was found most satisfactory.



being allowed to remain open and to dip in a beaker of the solution. When cool, any gas remaining in A was removed by gentle suction through C and the tap D was closed. The film was introduced into the body of the apparatus by momentarily removing the cork, and the gas was allowed to pass in through C, the flow being regulated by the tap D. There was no difficulty met with in preventing the film blocking up the tap D during the filling if the apparatus was maintained in a sloping position. These vessels were kept submerged under water and exposed to sunlight for about 8 days. At the end of this period the tap D was opened, whilst still under the water, and after equalising the internal and external pressure, the volume of the residual gas was measured and an analysis made. The observed decrease in volume varied considerably, but in every case the analysis disclosed considerable changes in the composition of the original gas.



The results of two typical experiments are given in Table I.

TABLE I.

Showing the effect of the film on the soil gases in sunlight and in the presence of oxygen.

cc. NT. & P.

				EXP. No. 1.			EXP. No. 2.		
				Before.	After.	Diff.	Before.	After.	Diff.
CO ₂	..	..	..	210.6	60.3	-150.3	49.5	Nil.	-49.5
O	..	..	..	156.6	285.8	+129.2	29.1	40.5	+11.4
CH ₄	..	..	..	98.8	66.4	-32.4	56.1	26.9	-29.2
H	..	..	..	Nil.	..	..	4.0	..	-4.0
N	..	..	..	24.0	27.7	+3.7	3.4	4.6	+1.2
TOTAL	..	..	..	490.0	440.2	-49.8	142.1	72.0	-70.1

In every case the volume of oxygen increased, whereas that of methane and carbon-dioxide decreased. Considering experiment No. 1, if the methane which disappeared were oxidized to carbon-dioxide and water, 64.8 cc. of oxygen would be required and there would be 32.4 cc. of carbon-dioxide formed. Consequently, during the whole course of the experiment there would be present 243 cc. of CO_2 , but of this amount only 182.7 cc. have disappeared. On the assumption that the CO_2 which disappears is decomposed by chlorophyllaceous algæ it would yield 182.7 cc. of oxygen, thus making the total volume of oxygen present during the course of the experiment equal to 339.3 cc. From this volume it is necessary to deduct the 64.8 cc. utilized for the oxidation of the CH_4 , leaving a balance of 274.5 cc. at the end of the experiment. As a matter of fact 285.8 cc. were actually found and the difference is probably accounted for by the CO_2 dissolved in the small amount of liquid present in the tube and which would not appear in the analysis.

Applying the same argument to Expt. II, the volume of oxygen which was theoretically recoverable was 47 cc. and 40.5 cc. were actually recovered.

Thus it is possible, on a quantitative basis, to explain the changes which occur by assuming that the film is capable of oxidizing the methane of the soil gases on the one hand, and on the other of decomposing the CO_2 thus produced with the liberation of an equal volume of oxygen. Green algæ are generally a constituent of the film, whilst diatoms are invariably present, and it would appear probable that the decomposition of the carbon-dioxide was due to these organisms. Further the film always contains bacterial growths and the oxidation of the methane and hydrogen is probably brought about by their agency.

If this were the case then the decomposition of the CO_2 should be inhibited by carrying out the experiments in the dark and the action of the film merely confined to oxidizing the methane. To test this the experiments were repeated in an identical manner but

the glass vessels were kept in darkness in the incubator at 32°C. for a period of about 10 days. At the end of that time the volume of gas remaining was measured and analysed with the following results :—

TABLE II.

Showing the action of the film on CO₂ and CH₄ in the presence of O and in darkness.

cc. NT. & P.

EXPERI- MENT.	FILM No. I.			FILM No. II.			FILM No. III.			FILM No. IV.		
Type of film used.	A whitish growth containing very little green algæ.			Consisting mainly of nostoc.			Mainly oscillatoria and a white growth.			A brownish growth containing a large number of diatoms and a white growth.		
	Before.	After.	Diff.	Before.	After.	Diff.	Before.	After.	Diff.	Before.	After.	Diff.
CO ₂ ..	26.7	39.4	+12.7	26.7	26.8	+ 0.1	26.7	38.0	+11.3	18.0	21.4	+ 3.4
O ..	77.8	41.1	-36.7	77.8	24.2	-53.6	77.8	31.5	-46.3	60.1	45.3	-14.8
CH ₄ ..	28.9	5.3	-23.6	28.9	0.6	-28.3	28.9	0.9	-28.0	34.5	26.9	- 7.6
N ..	6.6	6.4	- 0.2	6.6	8.2	+ 1.6	6.6	6.2	- 0.4	7.4	6.4	- 1.0
TOTAL	140.0	92.2	-47.8	140.0	59.8	-80.2	140.0	76.6	-63.4	120.0	100.0	-20.0

These results clearly show that the oxidation of the methane was not affected by the absence of light, whilst in no case was there a diminution in the original volume of carbon-dioxide present, but, on the contrary, usually a very decided increase. The conclusion is evident, that the action of the film, so far as methane is concerned, is mainly due to two separate and distinct agencies. One possessing the power of oxidizing methane to carbon-dioxide, and which is independent of the action of light. The other being capable of decomposing carbon-dioxide with the evolution of oxygen and dependent upon the presence of sunlight. The agents in the latter case are undoubtedly the green algæ, diatoms, etc., which are universally present in the films.

In this series of experiments the production of carbon-dioxide is less than the amount which would be expected from the volume of methane which disappears, and this fact would argue the presence of a third agent in the film which possesses the power of assimilating carbon-dioxide as such without a corresponding liberation of oxygen.

The photo-synthetic action of the green algæ of the film is easily demonstrated by confining the latter in vessels filled with a gaseous mixture of carbon-dioxide and nitrogen and exposing them to sunlight for several days. The result of a typical experiment is given in the following table :—

TABLE III.

Showing the action of the film on CO₂ in sunlight.

cc. NT. & P.

				Before.	After.	Diff.
CO ₂	..	..	..	87.4	6.8	-80.6
O	..	..	..	9.6	81.2	+71.6
N	..	..	..	53.0	52.0	-1.0

Further, it was noticed that hydrogen also disappeared whenever it was present in the mixed gases, and in such proportion to the oxygen that it was apparent that oxidation to water had occurred. As an example of this action the result of a typical experiment is given below :—

TABLE IV.

Showing the oxidizing action of the film on hydrogen in the dark.

cc. NT. & P.

				Before.	After.	Diff.
CO ₂	..	..	..	1.9	4.3	+2.4
O	..	..	..	190.8	130.0	-60.8
CH ₄	..	..	..	26.8	27.1	+0.3
H	..	..	..	136.2	..	-136.2
TOTAL				355.7	161.4	-194.3

The ratio of the number of cc. of oxygen which have disappeared to those of hydrogen is $O/H = 1/2.2$, a proportion which points to the process being one of oxidation only.

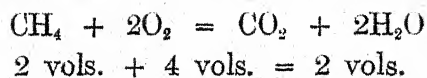
The experiments detailed above made it quite clear that the film (*a*) exerts a strong action on the soil gases, oxidizing the methane and hydrogen to carbon-dioxide and water, (*b*) can carry on the ordinary photo-synthetical processes of assimilating carbon-dioxide and liberating oxygen owing to the presence in it of chlorophyllaceous organisms, and (*c*) probably contains organisms capable of assimilating carbon-dioxide as such.

As the actions (*a*) and (*c*) are not inhibited by absence of light it was probable that the organisms bringing these changes about were bacterial in character and this hypothesis determined the trend of the latter portion of this investigation, the results of which are detailed in the following pages.

The oxidation of methane.

About 25 cc. of Kaserer's mineral nutrient solution was introduced into a Botkin culture flask, the gas leading tubes of which were plugged with sterile cotton-wool, and the whole was sterilized in the autoclave.

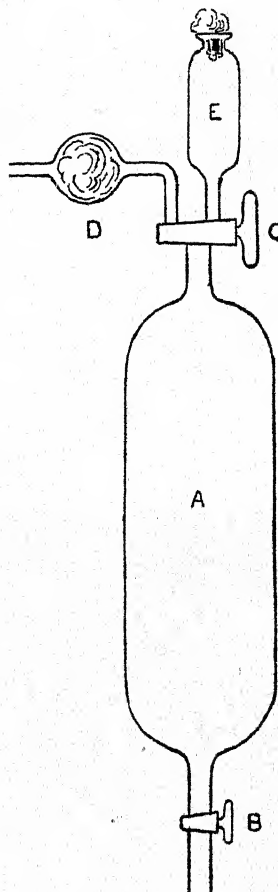
The solution was then inoculated with a very small piece of a film and a mixture of oxygen, nitrogen and methane was slowly bubbled through until the air in the flasks was displaced. After incubation at 32° C. for several days, a strong white film had formed inside the flasks and there was a partial vacuum caused by the oxidation of the methane—



By repeated transfers into fresh solution the crude culture was purified until there appeared to be only very few bacterial species present and the mixed culture thus obtained exerted a strong oxidizing action on methane.

The experimental methods adopted in order to obtain a quantitative measurement of this oxidation were as follows :—

The apparatus used is shown in the annexed sketch and consists of a cylindrical vessel A having a single bored stopcock B sealed on to the lower end, and a double bored one C to the other end. The double bored stopcock communicates on the one hand with the bulb tube D, the bulb of which was filled with cotton-wool, and on the other hand, with a small cylindrical vessel E having a capacity of about 10 ccs. and closed with a plug of sterile cotton-wool. In practice, the vessel A is filled with the mineral nutrient solution by means of suction through D, the tap B being opened and placed in a beaker of the liquid. Tap C is then closed and after introducing a little of the solution into E, the whole is sterilized in the autoclave, the end B remaining in the beaker with the tap open. When cool, a gentle suction at D removes any air remaining in A and then both the taps are closed.



The culture solution in E is inoculated with the crude culture and D is connected to a gas-holder containing the mixed gases. The latter are drawn into the vessel A by opening the taps C and B, the velocity being regulated by tap B. When nearly filled with the gas, the tap B is closed and the vessel A connected to the smaller vessel E. A little gas is expelled from A by the warmth of the hand and on cooling, the contents of the vessel E are drawn into A and the inoculation is accomplished. The taps are then securely closed and the whole apparatus is immersed in a vessel of water and incubated at 32° C. for several days.

At the end of the incubation period the vessel is removed, dried and weighed, and then the tap B is opened under water. Water rushes in to replace the gases which have disappeared and after equalizing the internal and external pressures, the vessel is again weighed. From the increase in weight obtained, the volume of gas which has disappeared is calculated. The volume of residual gas is measured by transference to a gas burette and an analysis is made. The results of several typical experiments with different crude cultures are given below :—

TABLE V.

Showing the oxidation of methane by the crude culture.

cc. NT. & P.

	Exp. I (14 days).			Exp. II (14 days).			Exp. III (21 days).		
	Before.	After.	Diff.	Before.	After.	Diff.	Before.	After.	Diff.
CO ₂ ..	1.7	14.7	+13.0	0.4	18.3	+17.9	0.6	14.4	+13.8
O ..	80.8	59.6	-21.2	53.7	14.8	-38.9	80.6	50.5	-30.1
CH ₄ ..	51.0	22.1	-28.9	33.2	10.6	-22.6	49.7	32.6	-17.1
N ..	9.3	7.7	-1.6	6.2	3.4	-2.8	9.2	4.5	-4.7
TOTAL .	142.8	104.1	-38.7	93.5	47.1	-46.4	140.1	102.0	-38.1

These experiments show that the bacteria composing the mixed culture exert a very strong oxidizing action on methane, but at the same time it is noticeable that the ratio of the volumes of the methane and oxygen which disappear is not in accordance with the theoretical, being 1/0.7, 1/1.3 and 1/1.8 respectively instead of 1/2. Further in the oxidation of methane the ratio between the CO₂ produced and the oxygen used is 1/2, and in these experiments the ratios found are 1/1.6, 1/2.2 and 1/2.2 respectively, a result much nearer the theoretical than that obtained for the oxygen-methane ratio. These considerations lead to the conclusion that a considerable proportion of methane has been assimilated direct. Söhngen¹

¹ Söhngen, *loc. cit.*

reports a similar result. In one of his experiments 225 cc. of methane and 148 cc. of oxygen disappeared, whereas only 99 cc. of carbon-dioxide were obtained, and at the same time considerable amounts of organic matter were produced. He concludes that this is due to the direct assimilation of methane.

Although this similarity between our results and those of Söhngen is apparent, yet by following out Söhngen's methods we have been unable to isolate the *Bacterium Methanecus* which he obtained, and neither have we been able by other methods to isolate any bacterium which in pure culture in mineral solution possessed the power of oxidizing methane.

It would therefore appear that there are in these rice soil films a number of species of bacteria acting together in symbiosis, the resultant being the oxidation of methane to CO_2 and the probable formation of some organic matter.

Notwithstanding our failure to isolate a specific methane-oxidizing bacterium, our main contention that this oxidation is due to bacteria must be taken as proved.

A photograph of the organisms present in the crude culture $\times 1,000$ diameters is given in the plate.

The oxidation of hydrogen.

We have previously referred to the fact that the surface film on rice soils possesses, to a considerable degree, the power to oxidize hydrogen, and, consequently, following out the line of experiment detailed under the section dealing with the oxidation of methane, we obtained crude cultures of bacteria in mineral solution which also possessed the same power in the presence of CO_2 and CH_4 . These crude cultures were purified by repeated transfers into sterile mineral nutrient solution contained in Botkin flasks and incubating in an atmosphere of oxygen, hydrogen and methane.

To illustrate the action of the mixed cultures thus obtained the results of two typical experiments are given below; the method of experiment being that previously described on page 9.

TABLE VI.

Showing oxidation of hydrogen by crude culture.

cc. NT & P.

				Exp. I (7 days incubation).			Exp. II (14 days incubation).		
				Before.	After.	Diff.	Before.	After.	Diff.
CO ₂	..	..	..	1.5	0.8	-0.7	1.3	0.6	-0.7
CH ₄	..	..	..	12.6	10.4	-2.2	11.4	6.9	-4.5
O	..	..	..	37.3	31.5	-5.8	33.6	14.4	-19.2
H	..	..	..	35.3	23.0	-12.3	31.8	Nil.	-31.8
N	..	..	..	19.3	19.3	Nil.	17.4	21.2	+ 3.8
TOTAL ..				106.0	85.0	-21.0	95.5	43.1	-52.4

The ratio of the volumes of oxygen and hydrogen which disappear are approximately 1/2.1 and 1/1.7 respectively as against the 1/2 required theoretically, a result which points to the action being one of oxidation only, particularly as there is no increase in the volume of CO₂ present, as would occur, if the methane were also subject to oxidation.

Further if the assumption is made that the methane is oxidized to CO₂ and the latter assimilated as such, then ratios of the balance of the oxygen used up to the hydrogen which disappears would be approximately 1/9.8 and 1/3.1 respectively. It therefore appeared probable that the mixed culture derived its carbon mainly from the methane and that the oxidation of the hydrogen yielded energy for the metabolic processes.

A photograph of the organisms present in the crude culture $\times 1,000$ diameters is given in the plate.

As our main purpose in this paper is merely to demonstrate the functions of the bacteria present in the films, we do not propose entering into great detail here relating to the functions of the specific bacteria isolated. These we intend publishing at a very early date as a separate paper.

PLATE.

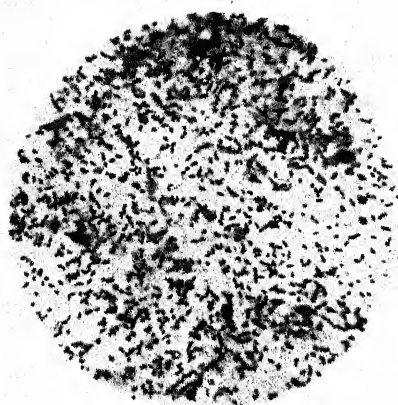


Fig. 1.

Bacteria composing the Crude Culture which oxidizes CH_4 X 1000.

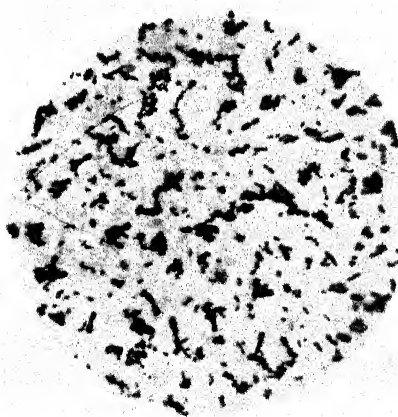
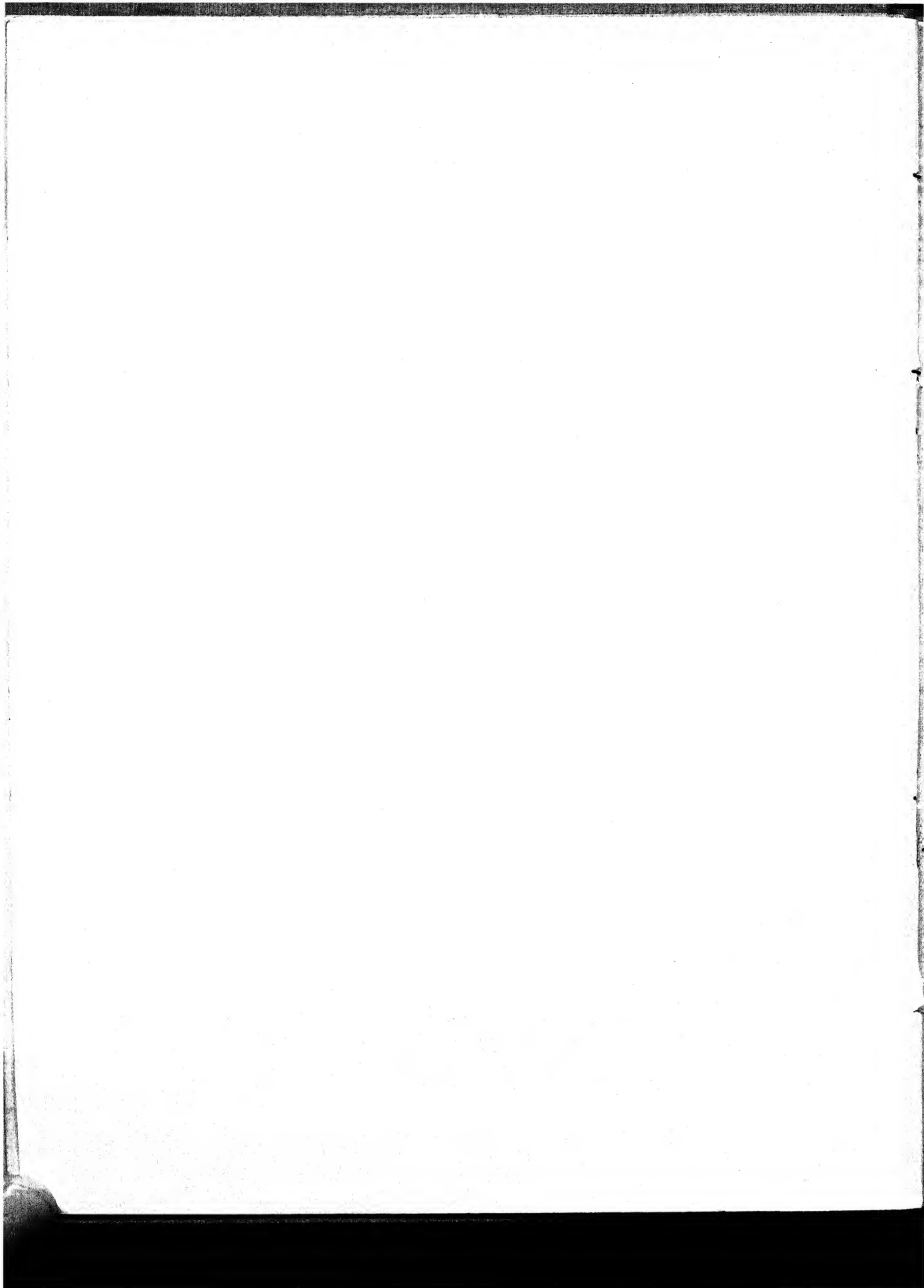


Fig. 2.

Bacteria composing Crude Hydrogen oxidizing Culture X 1000.



Briefly, we have succeeded in isolating an organism which oxidizes hydrogen to water in the presence of small amounts of nitrogenous organic matter. Various types of organic matter appear to affect the course and intensity of the action differently, and certain of them when used in excess practically inhibit it.

The organism grows very slightly under autotropic conditions and the action on hydrogen is correspondingly very feeble. In conjunction, however, with a second organism which we have isolated, autotropic oxidation of hydrogen takes place; carbon-dioxide forming the necessary carbon source. It is probable that there is here an interesting case of symbiosis, one bacterium providing organic matter for the other.

The experiment detailed in the following table shows the action of this bacterium in 0.02 per cent. sodium asparaginate solution.

TABLE VII.

Showing oxidation of hydrogen by bacterium No. 1 in mineral nutrient solution to which 0.02 per cent. of sodium asparaginate has been added.

Incubation period 10 days at 32° C.

				Before.	After.	Diff.
CO ₂	..	..	..	1.4	2.1	+ 0.7
O	..	..	..	139.0	126.6	-12.4
H	..	..	..	134.0	113.8	-20.2
CH ₄	..	..	..	2.3	1.5	- 0.8
N	..	..	..	11.6	12.8	+ 1.2
TOTAL				288.3	256.8	-31.5

As a result of this investigation it is evident that in the film there are organisms capable (1) of oxidizing hydrogen in the presence of minute amounts of nitrogenous organic matter, and probably (2) of assimilating carbon-dioxide directly and producing organic matter.

On the function of the surface film.

We have previously drawn attention to the function of the surface film in relation to the aeration of the roots of the rice crop, and also to the effect of green-manuring in increasing the effective aeration. In the absence of green manure the gas production in the soil is comparatively small, and consequently, the green algæ in the film must obtain their necessary carbon dioxide mainly from that dissolved in the irrigation water. When however green manures are used it has been shown that there is a largely increased output of the characteristic soil gases and that concurrent with this, there is an increased activity on the part of the surface film leading to an increased evolution of oxygen.

This relationship between gas production in the soil and oxygen evolution by the surface film we now demonstrate is due to the symbiotic relationships between the organisms found in the film. The methane mainly, and any hydrogen also which reaches the surface film, is oxidized with the production of carbon-dioxide and water, and the carbon-dioxide is in turn decomposed with the evolution of oxygen. Further, there appear to be organisms present which have the power of assimilating CO_2 and CH_4 under auto-tropic conditions, and the organic matter thus produced is probably utilized by the organisms responsible for the oxidation processes.

Consequently, in the film there is a community of different organisms which are capable of utilizing to the fullest extent the gases produced in the soil, and one in which the mutual relationships are so elastic as to be eminently capable of utilizing this energy and food-supply under a very great variety of conditions.

The oxygen thus liberated at the surface of the soil is in turn dissolved in the water entering the soil and is utilized for root aeration. In undrained or very badly drained soils this oxygenated water is unable to penetrate into the soil, and the roots as a consequence are restricted to the surface layer and stunted plants and poor crops are produced. In moderately drained soils on the other hand the slow downward current of water is, by contact with the

oxygen-evolving film, more highly aerated than is the case with water in contact with air only, and as a consequence there is a deeper root development resulting in sturdier and more productive plants.¹

It may possibly be objected that the oxidation processes taking place in the film use up much more oxygen than is recovered from the CO₂ produced, and that consequently there is actually less oxygen available for root aeration than would be otherwise the case. It is undoubtedly a fact that a maximum of only half of the oxygen required to oxidize methane can be liberated by the green algæ, and if the total oxygen supply were limited there would be decreased aeration.

But the oxygen supply to the film is not limited in any sense. These soils are kept covered with a shallow layer of water which is in constant circulation and which being in contact with the air is consequently nearly always saturated with oxygen at the atmospheric partial pressure. This layer of water thus acts as an oxygen carrier to the film and the supply of oxygen to the latter not restricted in the least.

The important aspect of the problem lies, not with the surface layer of water, but with that modicum of water which passes over the surface film and into the soil through the action of drainage. These Swamp Rice Soils are exceedingly heavy in character and the rate at which water drains through them is very slow, and, consequently, the latter, by passing through a film which is actively evolving pure oxygen, becomes more strongly aerated than does the surface water which is merely in contact with the air. The complete picture of the conditions is that of an organization acting as a concentrator of oxygen at the exact point where the most effective aeration of the water which enters the soil can be brought about.

One important result obtained from our experiments on the effect of drainage on the growth of the crop was the fact that

¹ Harrison and Subramania, *loc. cit.*, p. 101.

drainage exerted a beneficial action only when the rate was low, and that with high rates of drainage deterioration in the cropping occurred.¹ This we attempted to explain mainly on the basis that the strong downward current of water prevented the proper growth of the surface film, but in view of the results of the investigation now presented we feel that this explanation must be modified. That quick drainage does reduce the growth of the film was apparent on inspecting the surface of the soil, but over and above this aspect of the case we believe that the utmost importance attaches to the oxygen concentration in the water entering the soil.

In undrained soils the rate at which water enters the soil will depend solely on the transpiration of the crop. This rate will be extremely slow, but at the same time, the oxygen concentration in the in-going water will be high. The total oxygen, however, which can enter the soil will be small and its action will consequently be limited to the surface layer of soil; and in this layer only will root action be effective. As the rate of natural drainage increases, the volume of water entering the soil increases, and this water will possess the maximum oxygen concentration so long as more oxygen is produced by the film than can be dissolved in the in-going water. Thus, so long as these conditions hold good, the effective aeration of the roots will extend to an increasing depth followed by a corresponding increased cropping, and it is probable that the maximum effect will be reached at the point where the volume of in-going water is just sufficient to dissolve the evolved oxygen. Beyond this point an increasing rate of drainage will result in a lessening oxygen concentration and a decreasing root aeration and cropping; thus agreeing with the cropping results of our pot-culture experiments.

This theory also explains the curious fact that in our undrained and moderately drained pots, the weight of roots produced was practically the same, whereas in the quickly drained pots the weight of roots produced was greatly decreased.² After the point of

¹ Harrison and Subramania, *loc. cit.*, p. 97.

² *Ibid.*, p. 101.

maximum oxygen concentration is reached, the quick rates of drainage will still permit of deep root development, but the decreased concentration will result in a lessened amount of root production.

We therefore feel justified in putting forward the theory that one of the main factors which affects the growth and yield of the rice crop lies in the oxygen concentration of the water drawn into the soil through the combined action of drainage and transpiration.

SUMMARY.

1. The organized film in contact with the surface of Swamp Rice Soils utilizes the soil gases in such a manner as to bring about an increased oxygen output from the film leading to a correspondingly increased root aeration.

2. The film contains bacteria which possess (1) the power to oxidize methane and hydrogen, and (2) to assimilate directly methane and carbon-dioxide. These changes either directly or indirectly result in the production of CO_2 which is in turn assimilated by the green algæ with the evolution of oxygen.

3. The film may be looked upon as fulfilling the duty of an oxygen concentrator at a point which enables the maximum oxygen concentration to be produced in the water entering the soil.

4. The practice of green manuring by increasing the output of the soil gases brings about an increased activity on the part of the film resulting in an increased oxygen production and root aeration. An important indirect function then of green manuring is to bring about a greater root aeration and so induce greater root development and cropping power.

5. The oxygen concentration of the water entering the soil appears to be one of the main factors which regulates the growth of the crop.

COIMBATORE,

June 26th, 1914.

SOIL TEMPERATURES

BY

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INTRODUCTION.

DURING the last three years a record of the temperature of the soil has been kept at Pusa.

Certain records of the temperature of the soil down to considerable depths have been kept by the Survey and Meteorological Departments, but the agricultural student desires more especially correct information regarding the temperature of that stratum in which the plant roots develop, that is throughout the first two or three feet from the surface, and in respect of this subject the information in India is most limited.

Originally it was intended to maintain the record in fallow land with a smooth surface, and in similar land with a rough surface such as would result from rough ploughing, but the latter condition of the surface proved to be accompanied by errors of observation so great that the first record was limited to temperatures under a smooth surface. Subsequently crops were grown on the land and their effect ascertained.

It was hoped that by the aid of a careful record, general deductions regarding soil temperatures in arable land under Indian conditions would also be possible.

Apart from the errors which accompany the estimation of soil temperatures, there are a number of considerations which deserve remark.

The temperature of the soil is the effect resulting from a number of causes. First the colour of the soil is generally considered to have a marked effect. That the *colour* at the surface will have some effect on the absorption of radiant heat is well understood, but whether this effect is "marked" depends on what must be considered as deserving this qualification. Bouyoucos¹ concludes from a series of observations extending over a year, that "colour plays an important part in the warming of the soil," whilst an examination of his data shews that the difference of temperature between his darkest and lightest coloured soils was about 2° to 3° F. (1° to 1.5° C.) at 5" from the surface. As will become evident from the data to be discussed, such an effect, although not negligible, is still comparatively small. The *specific heat* of a substance which is suffering a change of temperature has naturally an important bearing on the rate of change of temperature, but Bouyoucos found dry soils of most varying descriptions to possess almost equal values in this respect. His estimation of the *conductivity* for heat of various soils shewed that the degree of variation amongst them was only small. On the other hand the *effect of water* in a soil was found, as was naturally expected, to be very much greater than that of all the other physical properties of the soil combined. The specific heat of water is so much greater than that of the soil material, that a wet soil necessarily requires much more heat—twice or even three times as much—to raise it through a specified range of temperature than the same soil when dry. The conductivity of a wet soil is very much greater than that of the same soil when dry. With the aid of all our knowledge of the physical properties of the soil material it is nevertheless quite impossible to forecast by their aid what the temperature of a soil may be expected to be under specified climatic conditions. It is a case in which the resultant effect can only be obtained by direct observation. Possibly however with the aid of records at one place, the soil temperature

¹ "An investigation of soil temperature and some of the most important factors influencing it," *Technical Bull. No. 17, Michigan Agricultural College Experiment Station.*

at another may be approximated, and this question is discussed subsequently.

The subject-matter of this memoir is considered under the following heads :—

- (i) Instruments employed.
- (ii) The data obtained.
- (iii) General deductions.

The *details* of the temperature record are added as an appendix.

INSTRUMENTS EMPLOYED.

Soil temperatures at other places have been recorded either by means of thermometers placed vertically or at slight inclination in the soil or by electric pyrometers buried at a suitable depth.

When I first decided to obtain a record on this subject, the electric pyrometer suggested itself as having considerable advantages over the thermometer. Enquiry of the Director of the National Physical Laboratory and of makers of these instruments indicated that this would not be necessarily the case. It appeared that although a thermocouple will shew slight changes of temperature, the error from the *actual* temperature may readily be several tenths of a degree centigrade. Again, unless the maxima and minima temperatures could be ascertained, the record would be extremely faulty ; owing to the lag in transmission of heat through the soil, these maxima and minima occur in succeeding strata at succeeding times, which are not readily ascertained, and occur during the night as well as during the day time ; consequently whatever instruments might be employed, they must be self-recording. The diurnal variation of temperature near the surface is commonly 10° to 15° C. and a chart shewing $1/10^{\circ}$ would require to be unusually large. The pen working on a drum is, owing to friction, very liable to pass into a *systematic* error which, unless it can be checked independently, remains undetected. It is then easy to realize how a self-recording pyrometer may be quite as seriously in error as a good thermometer. Apart from this consideration, the installation of the required number of

pyrometers,—about eight—would have been very costly. It was, on account of these several considerations, decided to employ self-registering thermometers of a good make. Such instruments are known to be liable to suffer from errors and these errors will be specially considered.

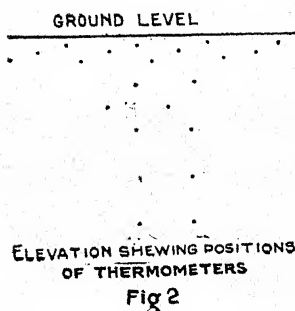
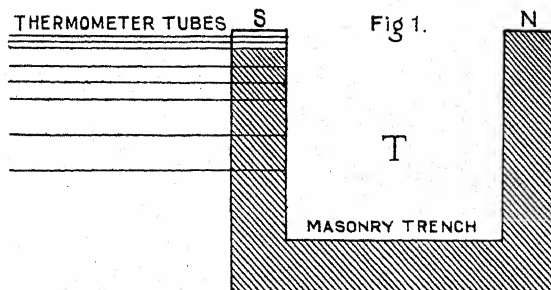
The soil.—A very brief description of the soil of this part of Bihar may be of interest to some readers.

It is a part of the great Alluvium and consists of very fine material devoid of stones or pebbles. It is peculiar in that it contains a very high proportion of calcium carbonate; between 30 and 40 per cent. of the soil material is fine chalk. On this account it possesses generally a much lighter colour than most soils. It holds water particularly well.

The site of the records.—Usually soil temperatures have been recorded by placing thermometers vertically into the ground. Instruments specially made for this purpose are purchasable, the thermometer being incased in a metal shield. Such an arrangement seemed to include an initial defect, for any such shield would be a much better heat conductor than is the soil. It appeared to be preferable to be able to insert the thermometer horizontally (from a distance) into the stratum of soil, and this method was adopted. A trench was dug east to west and the thermometers inserted horizontally southwards. As the sun's direct rays only strike a north face for a brief period in this latitude morning and evening, the face from which the thermometers were to be inserted would necessarily be hardly affected in this respect.

Another factor which was realized from some preliminary work was that although during the dry season (about 7 months) a horizontal hole for a thermometer could be made in the soil which remained intact, so soon as wet weather set in such holes silted up, and the north face also was liable to give way. This experience demonstrated the necessity for inserting durable tubes from the north face and also that the trench must be lined with masonry.

The nature of the tubes was another consideration. They should be, if possible, of non-conducting material. Glass was at first solely employed, but some of these fractured after insertion, and thus proved defective. On this account most of these were subsequently replaced by brass tubes. The complete arrangement which was finally adopted is illustrated in Fig. 1.



A trench T running E—W was lined with 10" masonry. It was 3 ft. deep by 3 ft. wide and allowed an observer sufficient space to withdraw and insert the instruments. At suitable positions in the south wall of this masonry, blocks of wood were inserted at the time of construction; and these blocks were drilled with $\frac{3}{4}$ inch horizontal holes. The positions of these holes are illustrated in Fig. 2.

Having constructed the trench, horizontal channels were drilled at the positions indicated by Fig. 2 from the wooden blocks into the soil to a distance of 3 ft. and tubes of glass or brass were inserted therein. Subsequently the positions of the further ends of the tubes at 1", 2" and 3" deep were found to be not exactly those which were intended. The thermometer bulb was naturally to be at the further (south) end of a tube, and it was essential that the distance of this from the ground-level should be that which was intended. On this account the tubes were withdrawn; the earth was excavated to the depth at which a tube was to remain, the tube placed in position and the earth then replaced and compacted. The *northern* ends of the tubes were inserted into the wooden blocks to a distance of 1" only.

Thus it was secured (*i*) that each tube rested on undisturbed soil at a specified distance from the surface, and (*ii*) that its northern end was protected by 9" of wood from the atmosphere in the trench.

Since the temperature recorded by a thermometer was essentially that of the south end of its tube, it is of importance to note that the distance of the south end of a tube from the ground level was smaller than that from the trench. The tubes were placed at 1", 2", 3", 6", 9", 12", 18" and 24" respectively, from the ground level, and as shewn in Fig. 1 it is evident that the further end of even the deepest tube was only 2 ft. from the ground level as against 3 ft. from the trench; in the case of those tubes in which great fluctuations of temperature occurred, the first five on the list, this disparity is very great. It might be argued that the *northern* ends of brass tubes at 18" and at 24" from the ground level are only 9" from the air of the trench, and that they would conduct heat more readily from the air of the latter than from the ground-level. Against this it is to be explained that (*i*) the diurnal variation at 18" is very small, and (*ii*) that whatever excess of heat might be obtained through the 9" of wood would become largely dissipated into the earth in contact with the northern portions of the tubes.

A much more serious reflection is, what is the real stratum of earth of which the tube and its thermometer registers the

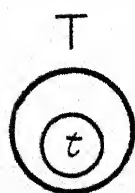


Fig 3

temperature? Fig. 3 illustrates the question. The outer circle 'T' represents a cross-section of a tube and the smaller circle 't' represents that of its thermometer bulb. The latter has a smaller diameter than the thermometer stem, and consequently does not touch the tube. The temperature recorded by the thermometer is the temperature of the air in the tube. The thermometer stems were about 0.6 inch diameter and consequently the tubes in which they rested were necessarily about 0.8 inch internal diameter. Is it to be assumed that the temperature of the air inside the tube

will approximate more nearly to that of the upper surface of the tube or to that of the earth all round the tube? The difference of temperatures near the ground surface is, for each 1/10", so great that this question is of considerable importance. It may be admitted at once that it cannot be answered very satisfactorily. But considering first the case of a brass tube, it may be assumed that owing to its high co-efficient of conductivity for heat, both the air within it as also its lower face, will rapidly assume the temperature of its *upper* face, *i.e.*, the temperature recorded by its thermometer will much more nearly approximate to that of its upper face than to that of the *mean* temperature of the soil above and below. Considering, secondly, the case of a glass tube, its co-efficient of conductivity is so small, approximately that of the soil, that it may be assumed that the air in it will approximate to the *mean* temperature of the soil above and below. Considering then two such tubes of equal diameter, to be placed at the same depth, say with their upper surfaces 1" from ground level, the temperature in the brass tube might be expected to be that of 1" from ground level, that of the glass tube to be $1\frac{3}{8}$ ". The difference of temperature might be expected to be frequently about 1° C. It was this consideration which led to the employment of tubes both of brass and of glass for the temperature records at 1", 2" and 3" from ground level. At greater depths the diurnal changes of temperature are so much smaller that the exact level to which the temperature registration refers is of less consequence. At first the data tended to show that the record in a brass tube was, for the maximum, distinctly higher, for the minimum distinctly lower than in the neighbouring glass tube, and there is little doubt that a real difference of several tenths-degree centigrade does occur. But an examination of the data covering two years shews that (i) the errors among the thermometers approximate to these differences; and (ii) that it does not exceed 0.5° C. It will be seen later that this inability to state what the real depth is (near the surface) to which a temperature refers has some significance; at the same time it should

be equally well realized that the difficulty cannot in any case be overcome. It is inherent in all such instruments, for no instrument, whether thermometer or pyrometer, has, in practice, such a small diameter that the factor which is now considered can be neglected.

The thermometers.—The thermometers were obtained from Messrs. Negretti and Zambra of London, and cost £1-1-0 each. They were graduated in $\frac{1}{2}^{\circ}$ C., and the reading could readily be made to $1/10^{\circ}$. Those registering maxima temperatures were mercurial, with a broken column. Those for minima temperatures were alcohol containing a metal indicator. They were all checked periodically in a large water bath against a standard mercurial thermometer possessing N. P. L. certificate, and the corrections for each were made in the records.

The records were made daily; at 6 A.M. the maximum thermometers were read, the indicators shaken down and then replaced in their respective tubes; at 10 A.M. the minimum instruments were similarly read, indicators adjusted and replaced. By replacing the thermometers at these hours it was insured not only that the time of maximum and minimum temperatures respectively had passed, but also that the positions of the indicators were for the former lower, for the latter higher than would be eventually taken up during the succeeding twenty-four hours.

The probable error of a temperature.—An examination of the records shews that these are open to both accidental and systematic errors. It is not possible to state precisely what the magnitude of these is, and the difficulty is especially great with regard to the latter class of errors. Fortunately the errors attaching to the thermometers near the surface were comparatively small; the only instrument which probably suffered from an error approximating to 0.8° C. was the maximum thermometer at 12" deep. In order to ascertain the errors attaching to the instruments as a whole the following data were examined. (i) The maxima at 1", at 2", at 3"; (ii) the corresponding minima; (iii) the

maxima and minima at 24". Regarding the temperatures at 1", 2" and 3" it has been explained that two thermometers were used at each of these depths, and that, although the temperature in a brass tube might be expected to be systematically higher than in a glass tube, actually the errors of the instruments obliterated this difference largely.

As a matter of fact the maximum instruments at 1" shewed no *systematic* difference, those at 2" shewed systematically a *higher* temperature in the brass tubes, those at 3" a systematically *lower* temperature in the brass tube; whilst the minimum thermometers all shewed *systematically* a slightly lower temperature in the brass tubes. Thus whilst the minimum thermometers shewed the brass tubes to influence the temperature by their better conductivity, the maximum thermometers did not. This being so, it was assumed for the purpose of estimating the probable error of any thermometer that there was no *real* difference between these temperatures and that the differences recorded by the thermometers were merely *accidental*. Again in respect of the temperature records at 24" deep, an examination of the data shewed that there was a daily rise or fall of about 0.2° C. for November and April. During February, March, October and December it was about 0.1° C.; that during all other months (of the record) the diurnal change of this depth is negligibly small. With this information to aid one, it was possible to calculate the probable errors of the thermometers generally. Thus the probable error of a—

maximum thermometer	<i>r</i>	Probability that the error is < .5° C.
at 1" =	± 0.22	9 : 1
at 2" =	± 0.37	2 : 1
at 3" =	± 0.23	6 : 1
minimum thermometer		
at 1" =	± 0.16	19 : 1
at 2" =	± 0.21	9 : 1
at 3" =	± 0.07	> 100 : 1
Probable error of either thermometer at 24" =	± 0.26	4 : 1

The last column shews what the probability is of any of these thermometers indicating a temperature 0.5° C. wrong. The

probability of an error of 1.0°C . is negligibly small. This calculation does not shew what errors attached to the readings at 6", 9", 12" and 18", but as the curves (presently to be discussed) shew, of these thermometers only the maximum thermometer at 12" has been more seriously at fault. Of the two classes, the minimum thermometers have shewn themselves the rather more reliable. It is true the alcohol column is somewhat apt to break up, but it is a defect which cannot be overlooked by the observer and has occurred 21 times among 577 observations. It is one which is of little consequence. It is seen that the probable error of a minimum reading at 1", 2" and 3" is distinctly smaller than the corresponding errors in the maximum data; and further, that whilst these alcohol thermometers shewed a systematic difference of the kind which was to be anticipated from the difference of tube, the errors of maximum instruments seem to have obliterated the effect of the material of the tubes.

THE DATA OBTAINED.

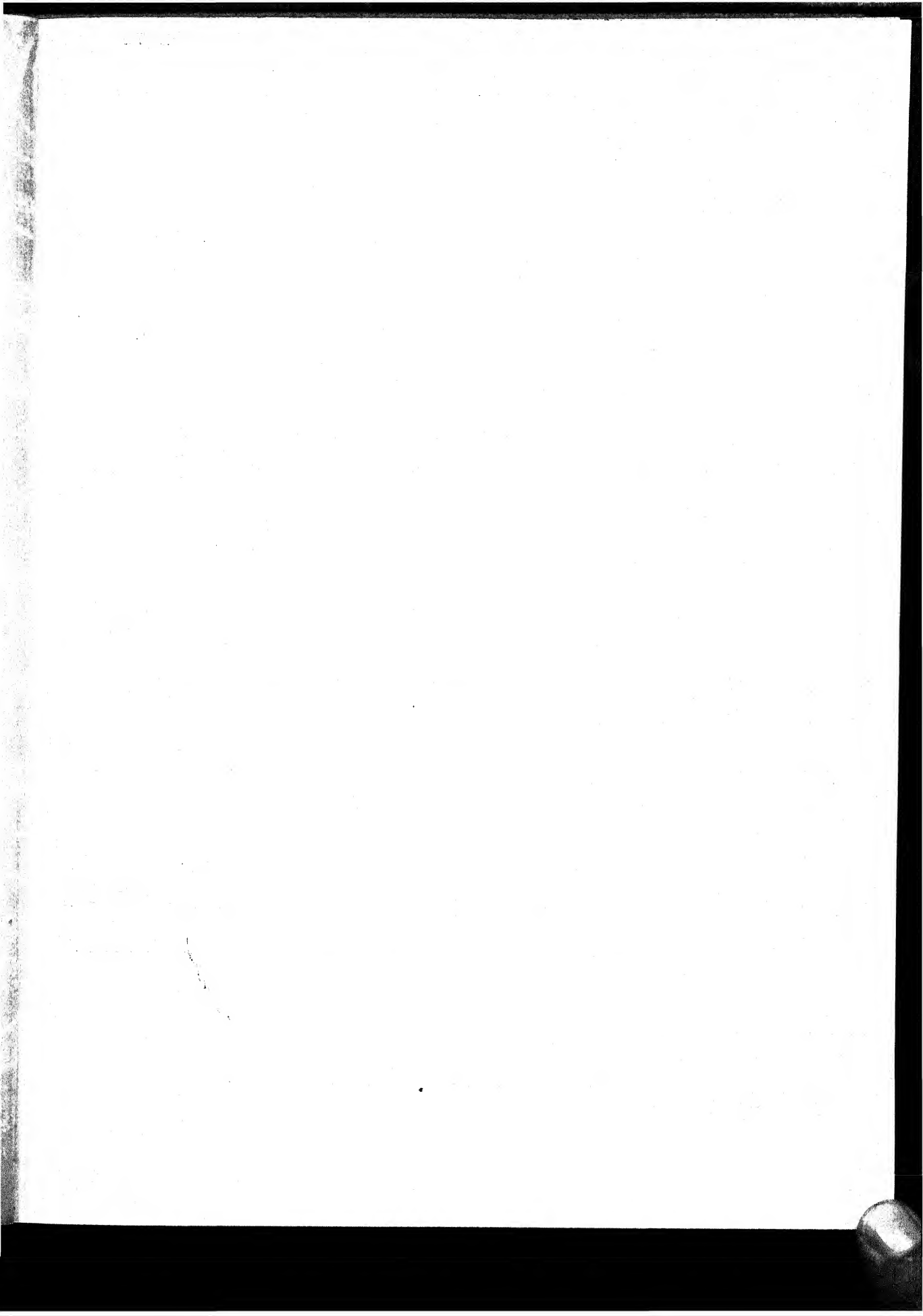
The daily records of soil temperature are set out in detail at the end of this memoir as an appendix, to which are added the rainfall and the daily maximum and minimum air (shade) temperatures.

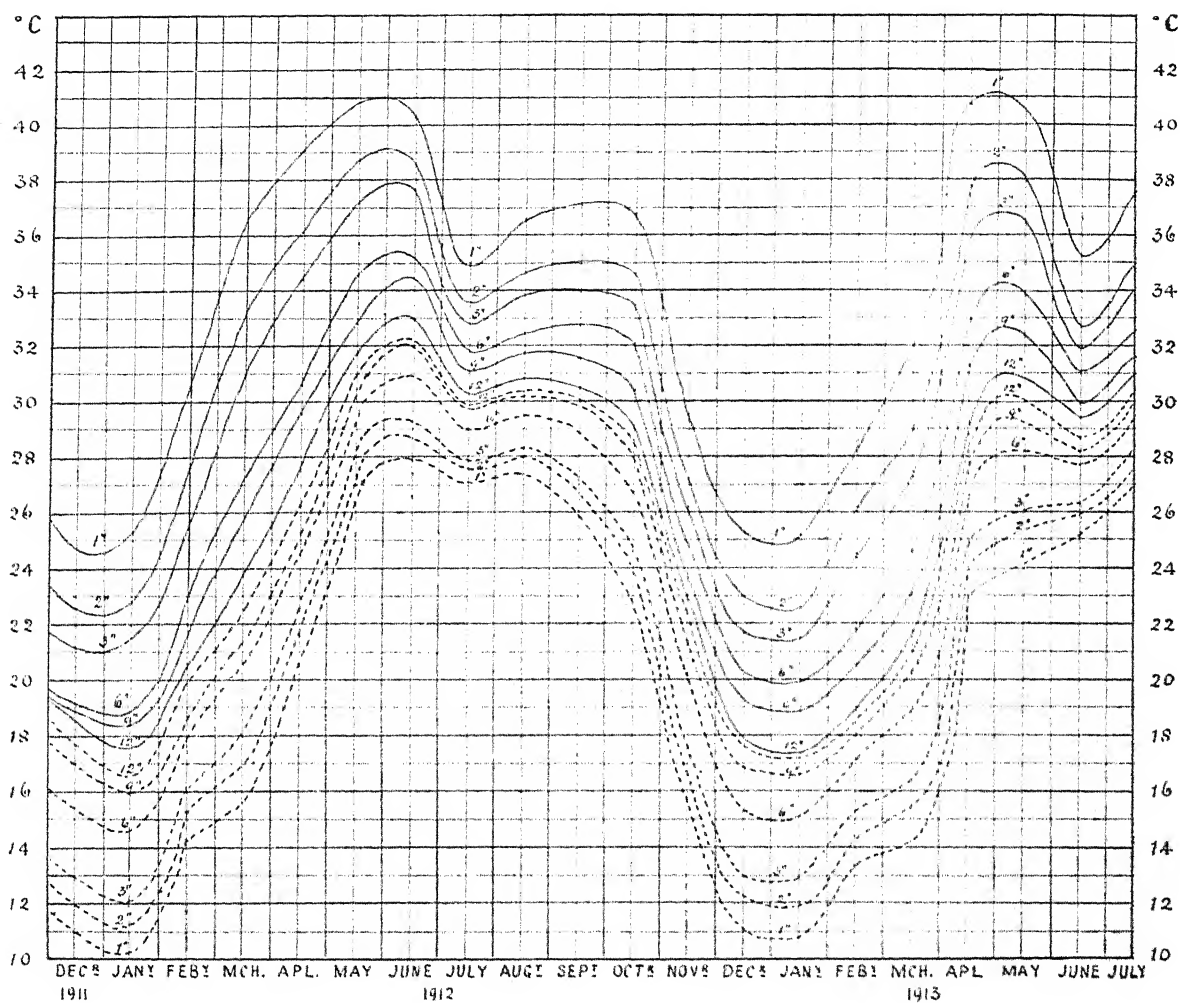
The information may be suitably considered under two chief sub-divisions:—

- (a) the temperature of bare fallow soil,
- (b) the temperature of cropped land.

(a). THE TEMPERATURE OF BARE FALLOW SOIL.

General.—The average temperatures for twenty months are set out in Table I, but variations of temperature are more readily appreciated with the aid of graphical representation. Such variations may be suitably charted in two ways, (i) by putting the ordinates = temperature and the abscissæ = time,





SEASONAL CHANGE OF TEMPERATURE.

and (ii) by putting the ordinates = depth in the soil, and the abscissæ = temperature. By the aid of the former, *vide* Fig. 4, each curve naturally refers to the temperature at a specified depth below the surface, and the changes of temperature which occur during the time interval are brought out. Provided the temperature changes are, for any particular time interval, not too great, and provided the curves do not cross one another, this mode of representation is very useful. In Plate I the changes of temperature of the soil with the season are thus shewn.

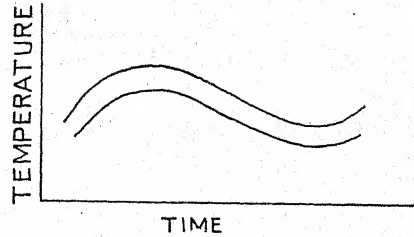


Fig 4.

There are altogether twelve curves; the six upper ones, drawn in continuous lines, refer to the maximum temperatures at the depths noted on each, namely, 1", 2", 3", 6", 9" and 12", the topmost naturally referring to 1" where the temperature becomes the highest during the day time; the six lower curves, drawn in broken lines, refer to the minimum temperatures at each depth. The two curves referring to 12" from the surface lie close together. Apart from other reasons, it would not have been useful to introduce any curves lying nearer together than these two, but, as will be seen presently, the curves for 18" and 24" deep would have overlapped some of the other curves, and consequently they have not been introduced on this chart.

This series of curves shew the main features of the changes of temperature with the seasons; such as the following:—

- (i) The lowest temperature occurs during January, from which time the temperature rises, and during February, March and April the rise is very rapid. The maximum of the season occurs in May.
- (ii) With the advent of the monsoon there is an immediate and rapid fall of temperature which is followed shortly afterwards by a small rise.

- (iii) The temperature of the soil suffers comparatively little change during the monsoon months, July to September.
- (iv) In October there is a rapid fall of temperature which continues until December.
- (v) The diurnal change of temperature is also well marked ; it is large during the months December to May and small during the monsoon months. These differences are more readily noticed on this chart in December to January, in May and in July to August when the temperature is more constant, and the curves consequently more or less horizontal.

The second mode of representing differences of temperature,

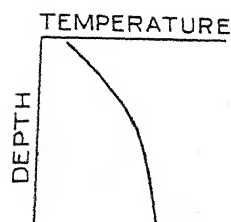


Fig 5.

in which the ordinates = depth and the abscissæ = temperature, *vide* Fig. 5, is more suitable for short periods of time, and brings out temperature differences at succeeding depths more perfectly than the first method. By the aid of a series of such charts the nature of the changes of temperature which the surface soil suffers is well demonstrated.

In order the better to appreciate the nature of the changes of temperature in the surface soil and to forecast what those changes may be expected to be, it is better to consider those for considerable depths. If the temperature record be kept to a depth where the *annual* change becomes zero, say 30 ft. or 40 ft. from the ground surface, and the data for maximum and minimum be plotted on a chart in which the ordinates represent depth and the abscissæ the temperature, curves similar to that in Fig. 6 will be obtained. These two curves will not represent the temperatures of *two* particular times because there is a

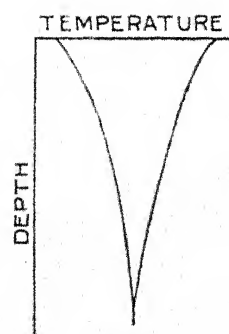


Fig 6

lag, and whilst the minimum near the surface will be reached in the coldest month of the year, that at lower depths will be reached during succeeding months; the same applies to the maximum temperatures. As a more definite illustration, a temperature record at Dehra Dun¹ may be quoted. The data are set out on page 37 and are also graphically set out on Plate VII. It will be seen that the minimum near the ground surface occurs in January, the maximum in June, which naturally coincide with the maxima and minima of the atmosphere. The minimum at 3 ft. occurs in February; the minimum at 6 ft. in February and the maximum in July to August; the minimum at 13 ft. in March and the maximum in September. At 25 ft. there is an annual temperature variation of 3° F. (1.6° C.) where the minimum occurs in May to June and the maximum in October to November.

Suppose now the temperature record be confined to the surface soil, and the daily minima and maxima are plotted, there will be obtained for the coldest day two curves x' , x'' , Fig. 7, the one, the minimum, being a part of the minimum curve for the whole depth down to the stratum of constant temperature, the other x'' (dotted) being the maximum for the coldest day. Similarly if the maximum and minimum of the hottest day in the year be plotted, there will be obtained two curves as at y' , y'' , the one, y'' the maximum, being a part of the maximum curve for the year, the other y' (dotted) being the minimum for the hottest day.

If this record of surface soil temperatures extends only to depth A, the minima and maxima curves will not meet at the lower ends, and will shew a *diurnal change* of temperature at the lowest depth 'A' for which the record is being maintained; if however the record is kept to a depth, B, at which there is no diurnal change, there will be only one curve in the lower part

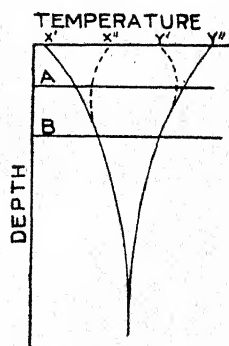


Fig 7.

¹ R. L. Jones, *Mem. Ind. Met. Dept.*, Vol. XV.

of the chart, this being a part of the *seasonal* curve. Moreover it is to be observed that, on the coldest day, whilst the minimum temperatures increase gradually from the surface, the recorded maxima *decrease* down to a certain point and then *increase* again ; similarly on the hottest day, whilst the maxima decrease uniformly, the minima increase down to a certain depth and then decrease again. We should have then in the cold weather a lower maximum at depth A than at B, and in the hot weather a higher minimum at A than at B.

This expectation is based rather on the assumption that the soil is a uniform conductor. This it is not ; the variation of proportion of water present in different strata influences the resulting temperature. It will be seen presently in how far the temperatures actually observed agree with the above anticipation.

Our Pusa records shew that there was a definite *diurnal* change at 12" from the surface, but that the change of temperature at 24" was certainly less than the experimental error, and probably there was no diurnal change here ; also that there was, over a part of the year, a very distinctly lower maximum temperature at 12" than at 24" (*i.e.*, similar to curve x", Fig. 7). The Pusa record then belongs to the second class above referred to, and each chart will include (apart from errors) not only the curves of diurnal minima and maxima, but also a part of the *seasonal* temperature curve. The case is not quite so simple as the illustration makes it appear, because the depth-limit of diurnal temperature variation is not constant. This depends on the magnitude of the range of daily air temperature ; during the monsoon this is only about 8° C. (14° F.) whilst in March and April it becomes about 17° C. (31° F.). There will then naturally be a diurnal temperature change to a greater depth during March and April than in July and August ; for the other months the limit of diurnal change will fall between the former and the latter,

TABLE I.
Average monthly temperatures of the soil; bare-fallow.

			1"	2"	3"	6"	9"	12"	18"	24"
January	1912	max.	25.6	23.0	21.6	19.1	18.6	17.1	18.1	18.5
		min.	10.9	11.9	12.7	14.9	16.2	16.8	17.5	18.2
	1913	max.	25.0	22.6	21.3	19.6	18.6	17.3	18.4	19.3
		min.	10.6	11.8	12.6	14.8	16.3	17.0	17.9	18.5
February	1912	max.	30.8	27.8	25.7	23.1	22.2	20.6	20.9	20.9
		min.	13.4	14.5	15.5	17.5	18.4	19.9	..	20.6
	1913	max.	27.9	25.6	24.1	21.8	20.9	19.8	20.1	20.4
		min.	13.8	14.7	15.6	17.3	18.3	18.8	19.2	19.7
March	1912	max.	35.9	32.8	30.8	27.2	26.0	24.0	23.9	23.9
		min.	15.7	16.9	18.1	20.7	21.4	22.7	..	23.4
	1913	max.	33.4	30.2	28.6	25.8	24.1	22.7	22.8	22.5
		min.	15.2	16.4	17.5	19.9	21.2	22.0	22.2	22.5
April	1912	max.	39.1	36.3	34.7	31.1	30.1	27.8	27.8	27.7
		min.	21.7	22.7	23.6	25.6	26.0	27.0	..	27.2
	1913	max.	40.7	37.8	36.2	33.2	31.5	29.5	29.1	28.4
		min.	22.9	24.1	25.1	27.1	28.1	28.7	28.7	28.5
May	1912	max.	40.5	38.5	37.1	34.7	33.8	32.0	32.1	31.9
		min.	26.6	27.6	28.3	30.0	30.6	31.2	31.2	31.5
	1913	max.	39.8	37.4	36.0	33.8	32.4	30.9	31.1	30.8
		min.	24.4	25.5	26.3	28.3	29.4	30.1	30.5	30.8
June	1912	max.	40.3	38.6	37.4	35.2	34.4	32.9	33.1	33.3
		min.	28.0	28.9	29.4	31.0	31.9	32.2	32.6	32.7
	1913	max.	36.1	33.8	32.8	31.8	30.5	29.9	29.9	29.8
		min.	25.8	26.5	27.0	28.3	28.6	29.2	29.5	29.9

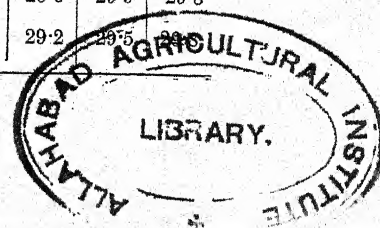
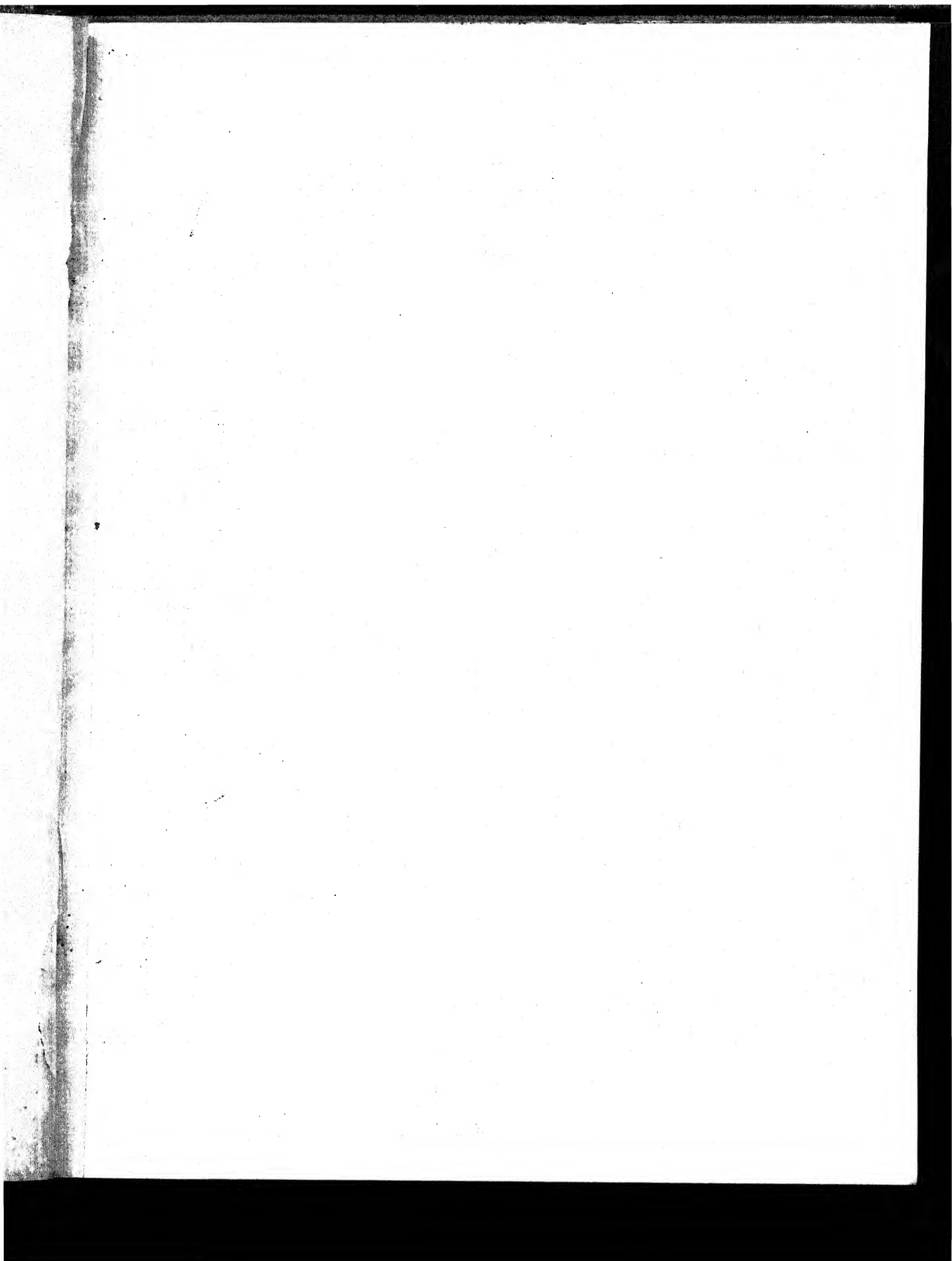


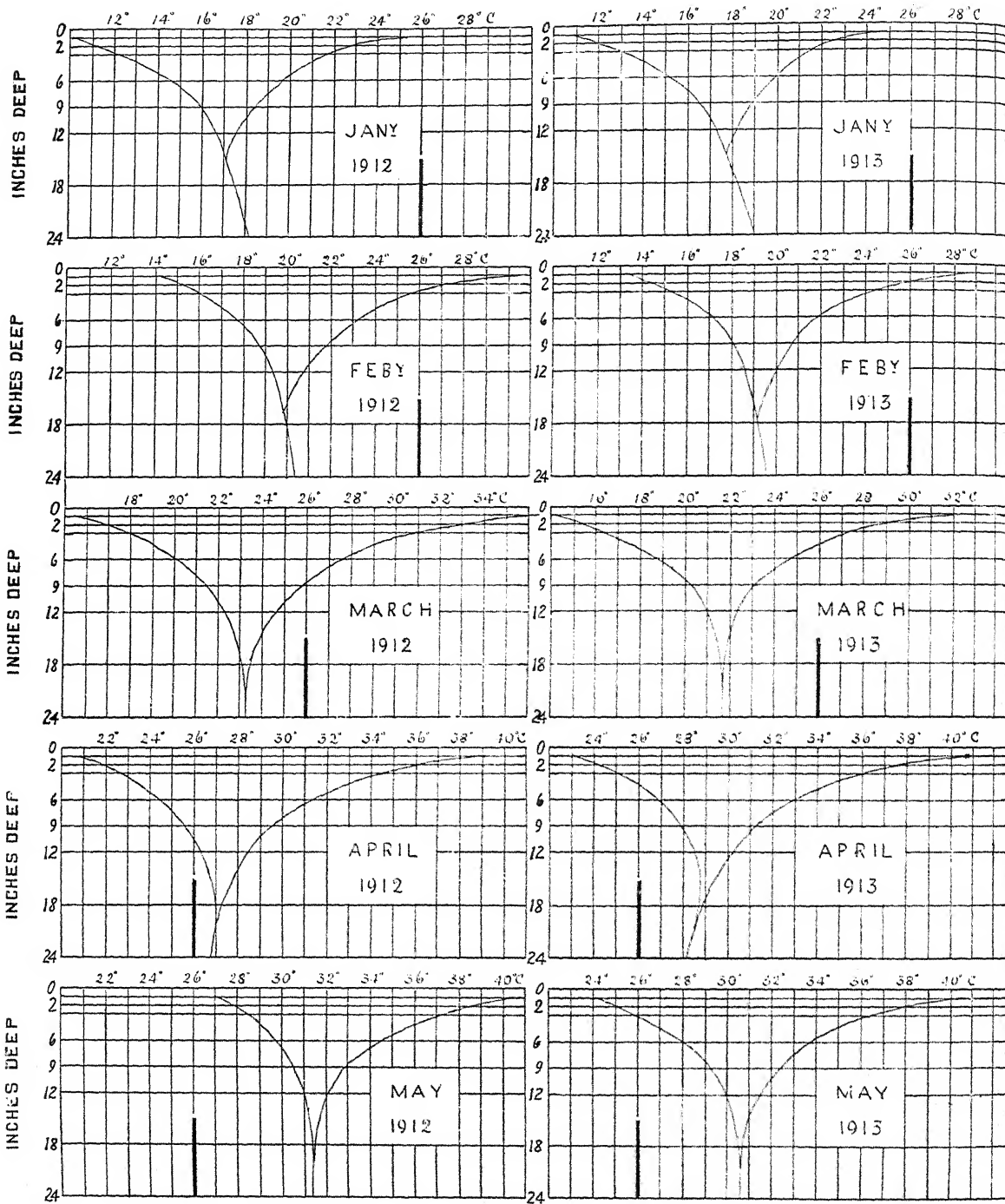
TABLE I.—(contd.)

Average monthly temperatures of the soil ; bare-fallow.

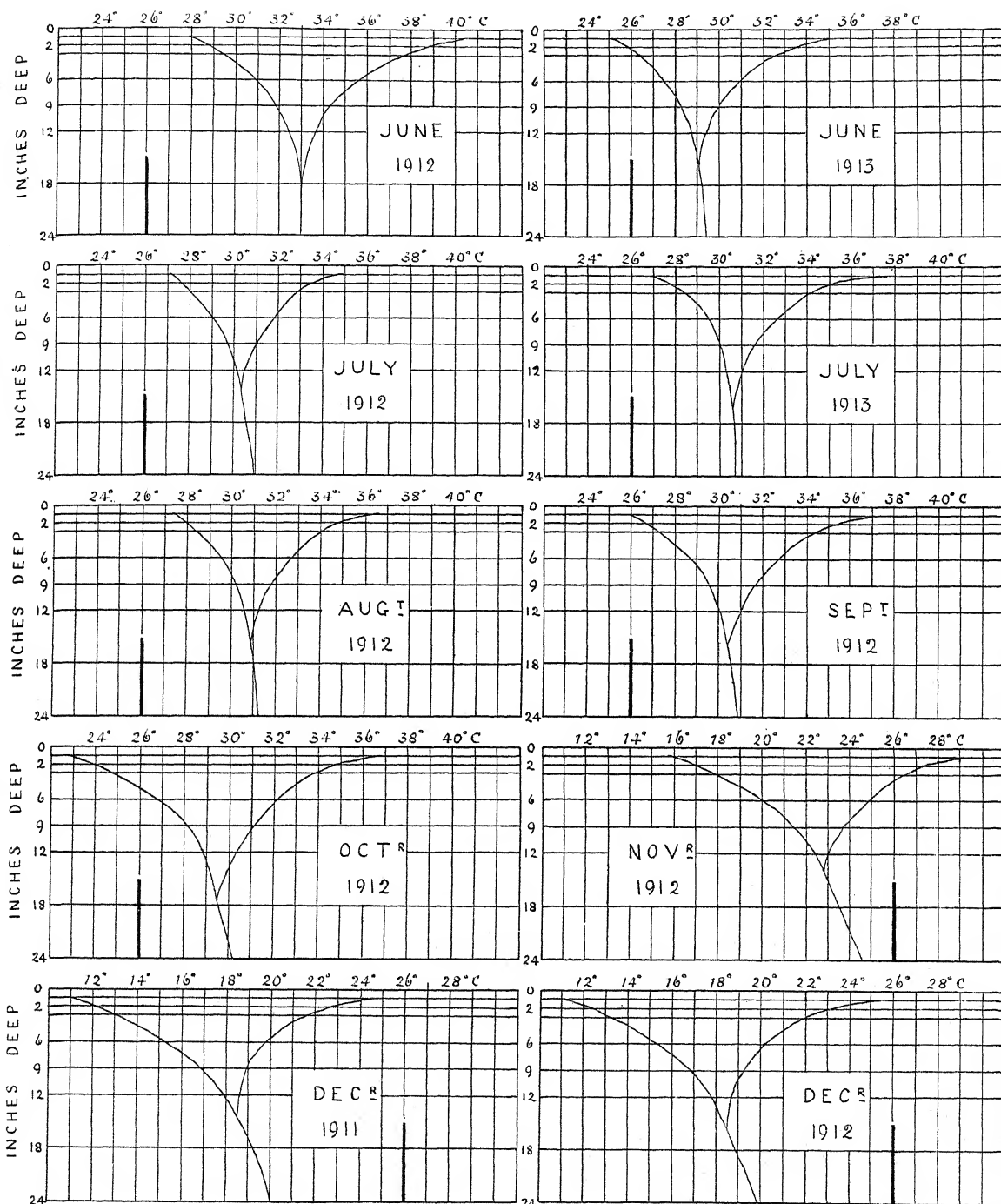
				1"	2"	3"	6"	9"	12"	18"	24"
July	..	1912	max.	35.0	33.6	32.8	31.8	31.2	30.3	30.7	31.3
			min.	27.2	27.4	28.0	29.1	29.8	29.9	30.3	30.6
		1913	max.	37.6	35.0	34.2	32.6	31.6	31.0	30.9	30.7
			min.	27.0	27.8	28.5	29.5	30.0	30.3	30.6	30.7
August	..	1912	max.	36.7	34.8	34.0	32.7	31.9	30.9	31.0	31.5
			min.	27.5	28.1	28.4	29.6	30.4	30.4	30.7	31.0
September	..	1912	max.	37.1	35.1	34.1	32.8	31.7	30.5	30.7	31.3
			min.	26.0	26.8	27.2	28.8	29.8	30.0	30.4	30.7
October	..	1912	max.	36.1	33.9	32.8	31.2	29.9	28.6	29.3	30.2
			min.	22.2	23.3	24.0	26.2	27.6	28.2	28.9	29.5
November	..	1912	max.	28.6	26.6	25.6	24.6	23.5	22.9	23.7	25.3
			min.	16.1	17.2	17.9	20.1	21.4	22.2	23.2	24.1
December	..	1911	max.	24.5	22.4	21.0	19.0	18.7	18.1	18.9	19.6
			min.	10.4	11.6	12.4	14.9	16.7	17.3	18.5	19.5
		1912	max.	25.4	23.0	21.9	20.2	19.1	17.9	19.1	20.2
			min.	11.3	12.4	13.1	15.3	16.9	17.7	18.6	19.5

Examination of the data.—For this purpose averages have been taken for each of the months, and they are set out in Table I. During and immediately subsequent to heavy rain, the temperatures become irregular and are separately considered. The monthly averages are also plotted on the series of small charts on Plates II and III to a depth of 24". Each of these is similar. The ordinates represent the depth from the surface, the abscissæ the temperature. In one respect it would have been advantageous to make each chart so long that the full annual range of temperature would be represented,





FALLOW LAND.



FALLOW LAND.

and had this been done, the gradual change in the position of the curves with the season would have been at once evident to the eye. Such would however have necessitated either charts of very much reduced scale, or the whole collection could not have been brought on to the two pages as they have been. But in order to aid the eye in following the displacement in the position of the curves as the season progresses, a vertical line has been drawn at 26°C on each chart. This is approximately the annual mean temperature both at 1" and at 24" from the surface. By bearing the meaning of this line in mind, it is readily seen how the curves change their relative position. In January, February and March the lower part of each curve is to the left of 26° , though they approach it in that order, with the seasonal rise of temperature. In April the lower part has passed to the right of the 26° line, and in May and June it is further to the right still. Then for the succeeding months July, August and September there is generally a somewhat lower temperature; in October the curve approaches the 26° line and in November and December it is to the left again.

The next point to notice is that although there is a measurable diurnal change of temperature at 12" from the surface, approximating to 1°C during the dry season, the diurnal change at 18" is usually quite small, and cannot be stated with accuracy.

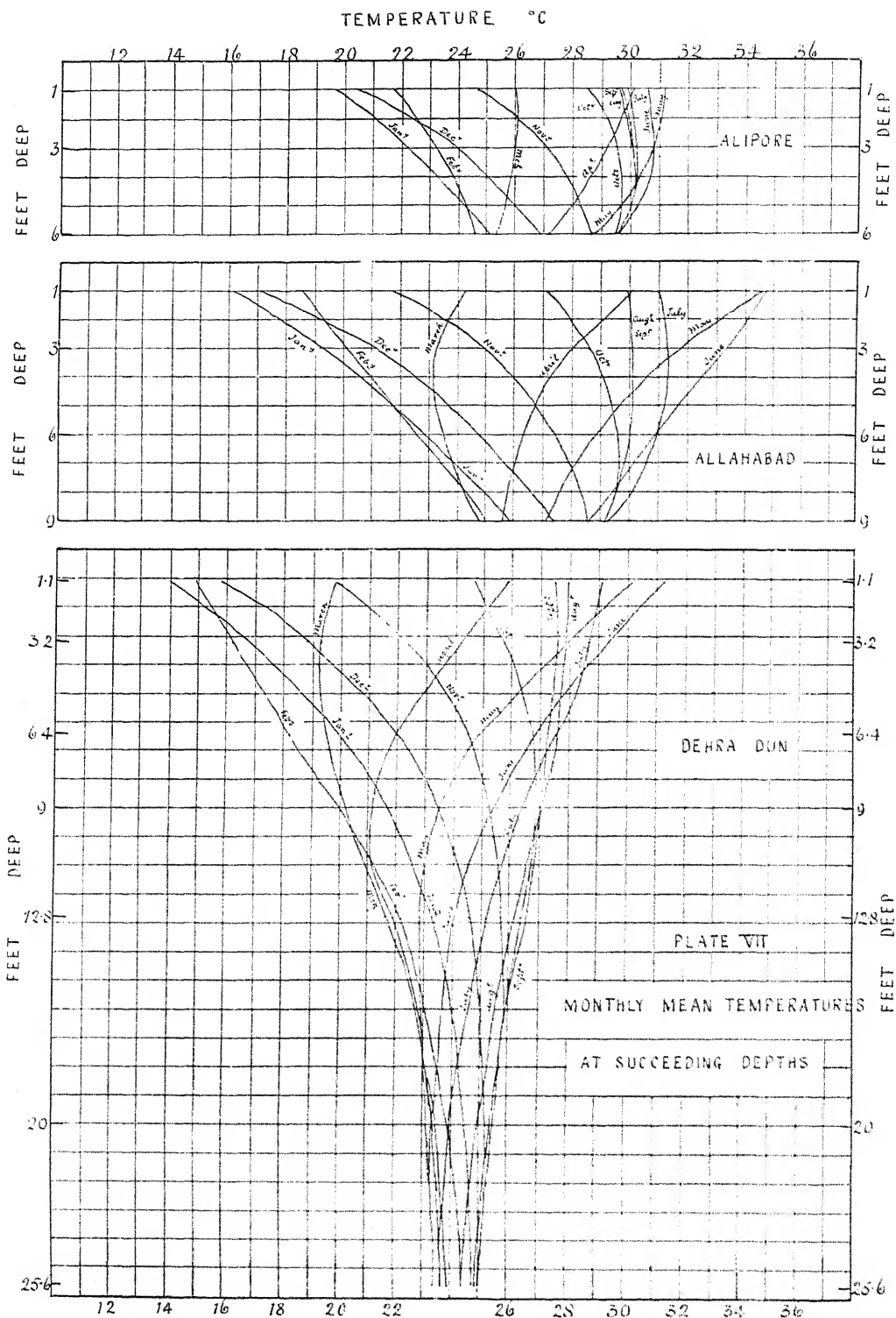
In drawing the curves of these charts, the direction of that for minima temperatures is nearly always more definitely indicated by the data than is that for maxima. This agrees with the deduction which was made from the probable error of the thermometers, namely, that the minimum instruments were the more exact. The curves have been drawn through the points representing observed temperatures or as near to these as a smooth curve could lie. The curves of temperature down to 9" seem to be definite, but at 12" and 18" there appears to be greater irregularity. At the same time the general direction of the lower end of the combined curve is definite. The distance apart of the upper ends of the curves shews the diurnal change of

temperature at 1" from the surface. It is seen that this diurnal change is considerable in January and increases to March and April. With the advent of the monsoon in June it becomes smaller and remains small during July to September after which it increases again during October to December.

Seasonal part of curves.—It is of considerable interest to compare the direction of the lower part of the curve in these charts with the curves for Alipore, Allahabad and Dehra Dun in Plate VII. Casting the eye over the (Pusa) charts Plates II, III, it is seen that for the months October to February the lower part of the curve appears to be a part of the minimum *seasonal* curve. For the other months the direction of this part of the curve is not what would have been anticipated from the consideration of the simple case which was illustrated in Fig. 7. Here a study of the curves for Alipore, Allahabad and Dehra Dun (Plate VII) at 1 to 2 ft. from the surface should be made, and compared with the charts for Pusa. Such a comparison shews how closely the temperature conditions from 1 to 2 ft. at Pusa agree with those at Alipore, but differ in several months (March, May and June) from those at Allahabad and Dehra Dun. These May and June differences are readily attributable to difference of monsoon conditions, because rain storms in advance of the monsoon occur in Bengal and Bihar causing damping of the soil in May, which do not usually occur at the United Provinces stations. The March difference is not so easily explained, but in any case the slope of the curve at any of the four stations is only small at this time of the year. These comparisons shew then that the lower part of the Pusa curves is actually what might be expected for the upper part of the seasonal curves.

Temperature change at 24".—Although, at Pusa, it is probable that the diurnal change of temperature at 24" deep is $< 1^{\circ}\text{C}$, a *seasonal* change naturally occurs, there being a small daily rise during some months, followed by a similar fall during





MONTHLY MEAN TEMPERATURES AT SUCCEEDING DEPTHS.

TABLE II.
Monthly mean temperatures of soil (°C) at Alipore, Allahabad and Dehra Dun.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
<i>Alipore</i>													
1 ft. ..	19.7	21.7	26.0	30.1	31.2	30.6	29.9	29.7	29.6	28.5	24.7	20.5	26.8
3 " ..	22.2	23.2	26.0	29.2	30.8	30.8	30.2	30.1	30.0	29.5	27.1	22.2	27.8
6 " ..	25.1	24.6	25.4	27.2	28.8	29.6	29.6	29.6	29.6	29.5	28.7	26.9	27.9
<i>Allahabad.</i>													
1 ft. ..	16.2	18.6	24.3	30.1	34.6	34.8	31.0	29.9	29.9	27.2	21.7	17.1	26.3
3 " ..	19.2	20.1	23.3	28.0	31.8	33.4	31.3	30.1	30.0	28.6	24.9	21.1	26.8
9 " ..	25.9	25.0	24.9	25.7	27.2	28.6	29.3	29.2	29.2	29.2	28.6	27.4	27.5
<i>Dehra Dun.</i>													
1.1 ft. ..	14.0	14.9	19.8	25.9	30.2	31.3	29.1	28.0	27.5	24.7	19.8	15.8	23.4
3.2 " ..	16.7	16.2	19.3	24.3	28.0	29.4	28.7	27.9	27.6	25.8	22.3	18.8	23.8
6.4 " ..	19.8	18.2	19.5	22.0	24.9	26.9	27.5	27.6	27.3	26.8	24.5	22.0	24.0
12.8 " ..	23.3	22.2	21.6	21.9	22.9	24.1	25.2	26.2	26.6	26.4	25.7	24.6	24.2
25.6 " ..	24.7	24.3	23.9	23.5	23.4	23.4	23.6	24.4	24.9	25.0	25.0	24.9	24.2

others. This change of temperature can be estimated from a comparison of the initial and final temperatures of any month, and the daily change, estimated in this manner, is set out in the following table.

TABLE III.
Mean daily change of temperature at 24."

January	..	..	..	..	..	+ 0.03
February	..	..	..	..	..	+ 0.14
March	..	..	..	..	..	+ 0.12
April	..	..	..	..	..	+ 0.13
May	..	..	..	..	..	+ 0.05
June	..	..	..	..	..	± 0
July	..	..	..	..	..	- 0.03
August	..	..	..	..	..	- 0.02
September	..	..	..	..	..	± 0
October	..	..	..	..	..	- 0.12
November	..	..	..	..	..	- 0.17
December	..	..	..	..	..	- 0.12

Temperature change near the surface.—As is to be expected from a poor conductor, such as the soil, the diurnal temperature variation near the surface is particularly great. The difference from 1" to 2" is 2° to 3° C in the day time, and the variation is obviously considerably greater than this between the surface and 1" deep.

Temperature at the surface.—Although the temperature which the soil assumes at the surface would be of considerable interest, it must be realized that it is not possible to measure it *directly*. For obviously an instrument must be either buried (however thin the covering layer of soil might be) in which case the temperature record would be that of a certain depth, or it must be *on* the surface in which case it might or might not register the same temperature as the soil surface. Extrapolation of the curves is also unsatisfactory especially for the maxima. The direction of the curves in the charts is simply that obtained by drawing the curves through the points of average monthly temperatures, and although the process of averaging will have obliterated the *accidental* errors, *systematic* errors are doubtless present. Nevertheless the direction of these curves shews very

clearly that the temperature at the soil surface is, during the day time, very far above that at 1" deep. With respect to the *maxima*, extrapolation would indicate for the dry season a temperature some 10° to 15° C higher at the surface than at 1" deep; during the rains the difference is usually considerably less. Another method of trying to form an opinion of the surface temperature is to consider that of a thermometer with blackened bulb enclosed in a vacuous glass vessel (the solar radiation thermometer) and exposed to the sun. This naturally is an extreme case, for not only is the exposed object black, but it is protected from loss of heat by convection air currents, whilst the soil is lighter coloured and its heat is constantly subject to reduction by convection air currents and by conduction through underlying soil. The following are examples of temperatures registered by maximum thermometers in the shade and in the sun at Pusa :—

				In Sun.	In Shade.	Difference.
				°C.	°C.	°C.
January 1st, 1908	..	..	..	51.9	24.4	27.5
January 1st, 1909	..	..	..	54.7	25.6	29.1
April 1st, 1908	..	..	..	66.8	39.6	27.2
April 3rd, 1909	..	..	..	70.0	40.0	30.0
May 1st, 1908	..	..	..	71.6	42.8	28.8
May 8th, 1909	..	..	..	74.5	43.4	31.1

It may be safely assumed then that the temperature of the soil at the surface is considerably less than 30° C above the air-temperature.

As regards the minima at the surface, the extrapolation of the curves is more definite because the slope is much greater. These indicate that the minimum temperature of the soil surface is, during the dry season, about 1° C below that at 1" deep, and about 0.5° C during the rains.

Relation between air temperature in shade and soil temperature at 1" deep.—The relation between air-temperature in shade and that at 1" deep is also of considerable interest and is seen from Table IV on the following page.

TABLE IV.

Comparison of Air and Soil Temperatures.

	MINIMUM.			MAXIMUM.			DIURNAL CHANGE.	
	Air.	Soil 1" deep.	Diff.	Air.	Soil 1" deep.	Diff.	Air.	Soil 1" deep.
January ..	9.1	10.7	+1.6	23.5	25.3	+1.8	14.4	14.6
February ..	11.6	13.6	+2.0	26.3	29.3	+3.0	14.7	15.7
March ..	13.8	15.5	+1.7	31.2	34.6	+3.4	17.4	19.1
April ..	20.6	22.3	+1.7	36.6	39.9	+3.3	16.0	17.6
May ..	23.0	25.5	+2.5	36.4	40.1	+3.7	13.4	14.6
June ..	24.5	26.9	+2.4	33.9	38.2	+4.3	9.4	11.3
July ..	25.6	27.1	+1.5	32.3	36.3	+4.0	6.7	9.2
August ..	25.5	27.4	+1.9	32.2	36.7	+4.5	6.7	9.3
September ..	24.1	26.0	+1.9	33.2	37.1	+3.9	9.1	12.0
October ..	20.2	22.2	+2.0	32.8	36.1	+3.3	12.6	13.9
November ..	14.1	16.1	+2.0	26.8	28.6	+1.8	12.7	12.5
December ..	9.2	10.8	+1.6	23.2	24.9	+1.7	14.0	14.1

The first fact to notice is that the minimum soil-temperature at 1" deep is always higher than the minimum air-temperature, the difference being about 1.5° to 2.0° C; and since the temperature of the soil surface appears to fall about 0.5° to 1.0° C lower than at 1" deep, one must conclude that the soil surface does not fall to as low a temperature as the air does at 4 ft. from the ground, which is the level of the air thermometers. Secondly, regarding maxima, the temperature of the soil at 1" deep is always greater than that of the air (in the shade), the difference being from 2° to 4° C.

The diurnal changes of air-temperature and of the soil-temperature at 1" deep respectively are shewn in the last column. During the dry months, January to May and October to December the diurnal change is about 13° to 17° C in the air, and about 14° to 19° C in the soil. During the rains these diurnal changes are about 7° to 9° C in the air and 9° to 12° C in the soil.

Soil temperature generally in India.—With the foregoing information as a guide, it seems reasonable to make certain deductions regarding the temperature of soils generally in India, with the exception of the black cotton soil which, owing to its

very dark colour, may become somewhat hotter at the surface than would be indicated by the results of Bouyoucos' records.

During dry weather with a clear sky, if 20°C be added to the maximum air-temperature in the shade, the sum will give the maximum temperature of the soil at the surface of *fallow* land, the error being about $\pm 5^{\circ}\text{C}$. The minimum temperature at the surface may be assumed to be that of the atmosphere. In the following table are set out the estimated temperatures of the soil for specified maximum air-temperatures :—

Air-temperature maximum		$^{\circ}\text{C}$. ($^{\circ}\text{F}$).	25° (77°)	30° (86°)	35° (95°)	40° (104°)	45° (113°)
Soil	at surface		47°	53°	59°	65°	71°
	at 1" deep		27°	33°	39°	45°	51°
	at 2" deep		25°	30°	36°	42°	45°
	at 3" deep		23°	28°	34°	40°	43°

During the monsoon, when the sky is cloudy, the difference between air-temperature and that of the soil surface is very much less, being not more than $2\text{--}3^{\circ}\text{C}$ higher than that at 1" deep. Soil covered with crops is very much protected as is seen from the data quoted subsequently.

As regards the *duration* of the above estimated maximum temperatures, this is quite short, and is certainly not more than 2 hours per day.

The hourly variation.—In order to ascertain the "lag" of temperature at succeeding depths; a series of two-hourly observations were made in the cold weather and hot weather 1913. The observations were made by means of the minimum alcohol thermometers. For this record the indicators were not employed, and were allowed to fall back into the bulb. When taking an observation, each thermometer was withdrawn from its tube only so far as to enable the observer to read the temperature coinciding with the bottom of the alcohol meniscus;

the bulbs were thus subjected to the smallest possible temperature change; each thermometer was then immediately replaced in position.

The two records are shewn in charts Nos. IV and V. The curves are not smoothed, but are drawn through the observed points. In these charts the ordinates represent temperature and the abscissæ time. The depth to which each curve belongs is noted on it. Naturally the curve for 1" deep crosses all the others, being the lowest at the time of minimum temperature and the highest at that of maximum temperature; that for 24" is a nearly straight line; the others take up intermediate positions. The minima and maxima *on the charts* occur at the hours specified in the following Table V, but it must be recollected that these hours are not really the precise times of maxima and minima, which would in fact occur generally at some time between two readings.

TABLE V.

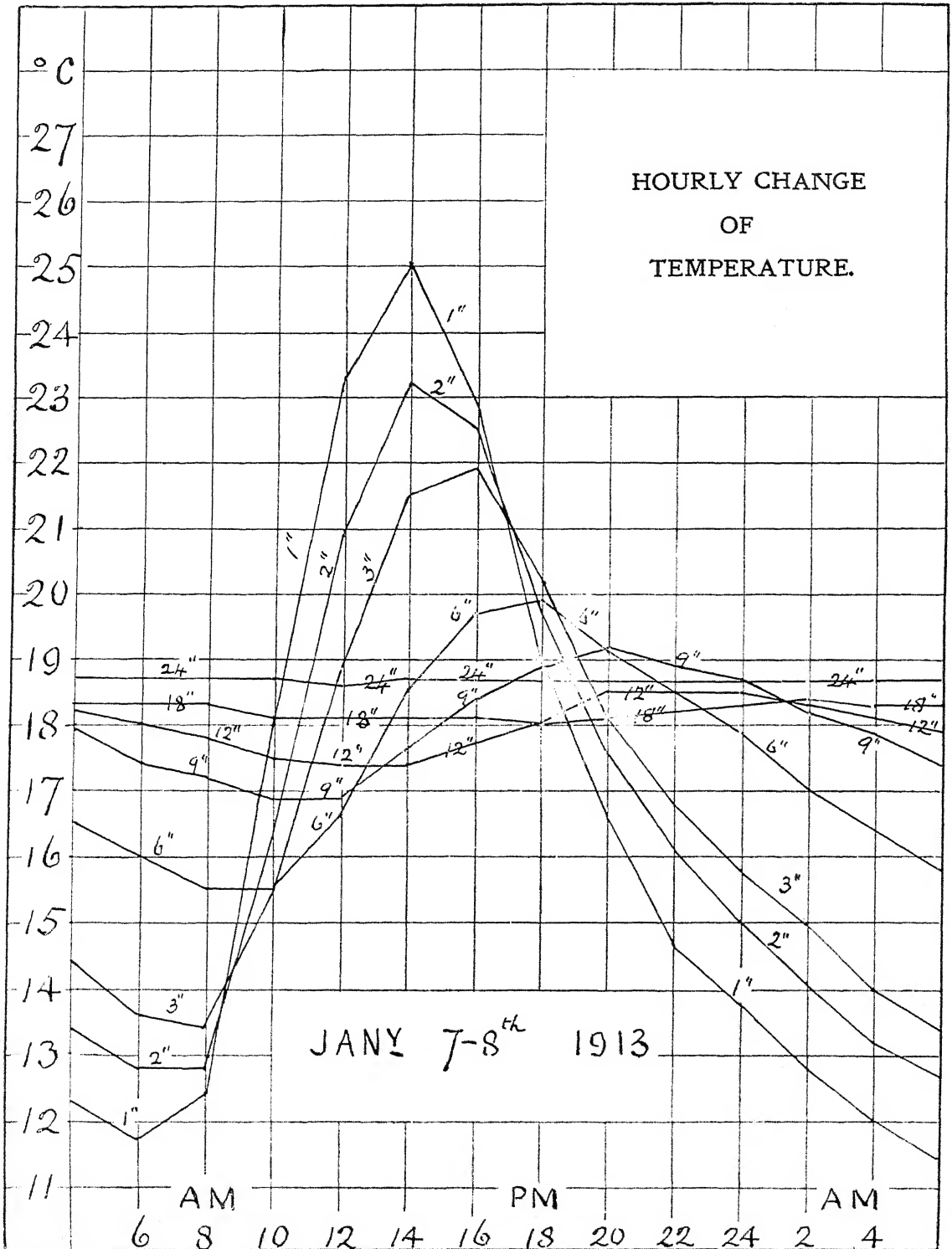
Showing the time of minimum and maximum temperature in the soil.

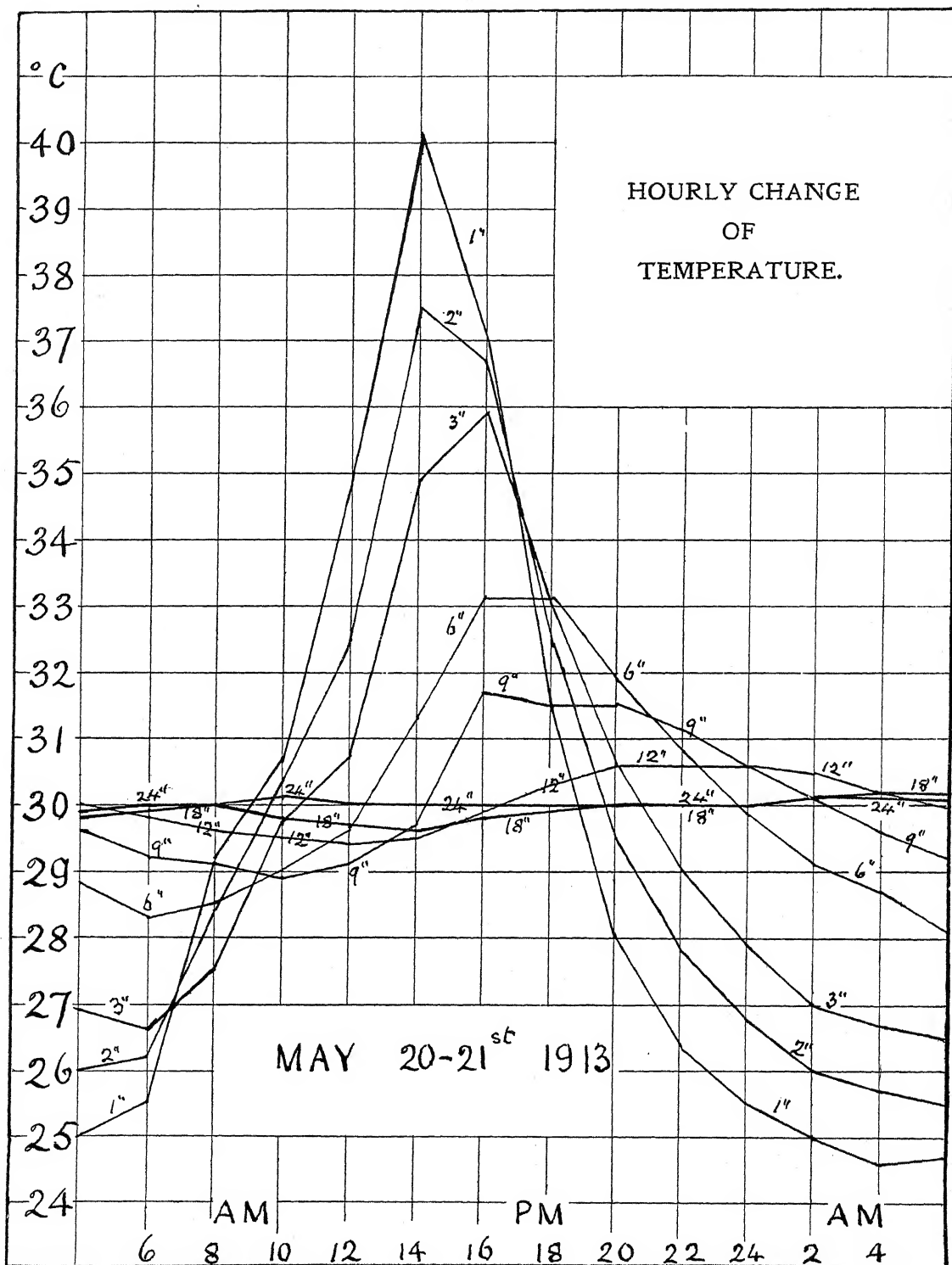
Depth.	COLD WEATHER.		HOT WEATHER.	
	Minimum	Maximum	Minimum	Maximum
1"	6 A.M.	2 P.M.	4 A.M.	2 P.M.
2"	8 "	2 "	4 "	2 "
3"	8 "	4 "	6 "	4 "
6"	9 "	6 "	6 "	5 "
9"	11 "	8 "	10 "	4 "
12"	2 P.M.	10 "	12 noon	10 "
18"	2 "	2 A.M.	2 P.M.	4 A.M.
24"	constant		constant	

NOTE.—This observation is obviously incorrect, but an error of 0.2 C would change this hour to 6 P.M.

It will be seen that the lag at 18" deep amounts to 8 hours.

From the charts it will be seen that the period of time during which the temperature at 1" deep was above the mean 24 hours temperature (approximately—but slightly above—that for 24")

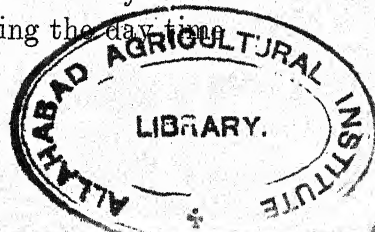




was very much shorter than below it. At both seasons the temperature (at this depth) was 8 hours above and 16 hours below the mean. Thus the soil acted as though it were a better conductor during the day time than during the night. The term is naturally incorrect, and the fact is due to the much higher temperature to which the *surface* of the land rises during the day time than does the air, whilst at night the soil-temperature only approximates to that of the air. Dew formation appears to have practically no influence, for during January there is a very heavy dew formation, whilst this is absent in May. The fact of the much more rapid heating than cooling of the soil is also reflected in the difference of temperature between 1" and 2" and between 2" and 3" deep; these differences are considerably greater at the time of maxima than at those on minima temperatures; it also accounts for the difference in the shape of this portion of the curves in the charts of Plates II and III. This fact does not seem to have been noticed by other observers.

The effect of soil-moisture on the soil-temperature.—The effect of water on both the specific heat and the conductivity of a soil has been briefly referred to in the Introduction. It remains to consider whether this effect of water influences the *soil-temperature*, and to what extent.

It is to be recollected that, although the specific heat and the conductivity of a soil are materially different according as the proportion of water present is low or high, it does not necessarily follow that the maximum or minimum temperature reached will be thereby affected. The increase of specific heat occasioned by an increase of soil-moisture would demand a correspondingly greater amount of heat to raise its temperature $x^{\circ}\text{C}$, but provided the damp soil is exposed to the source of heat for a sufficient length of time, it will attain the same temperature as when dry. The case of the exposed soil is not a simple one, because it is exposed to an atmosphere, the temperature of which is constantly changing. Theoretically a wet soil should not rise to as high a temperature during the day time

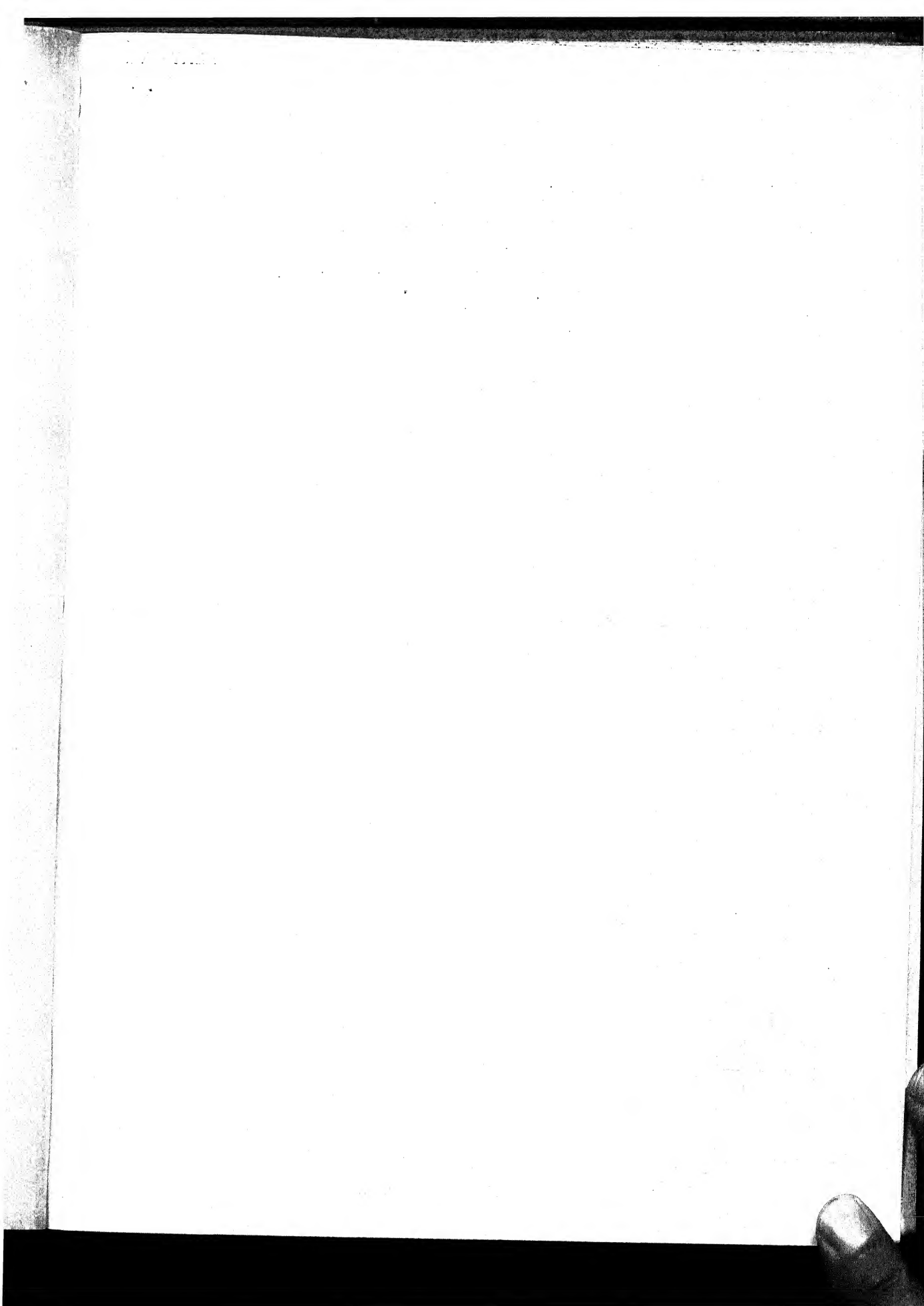


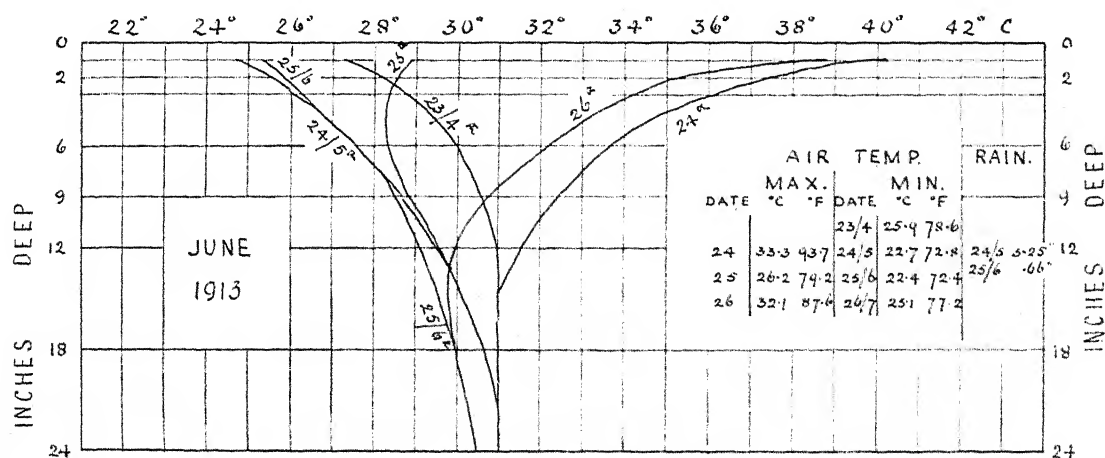
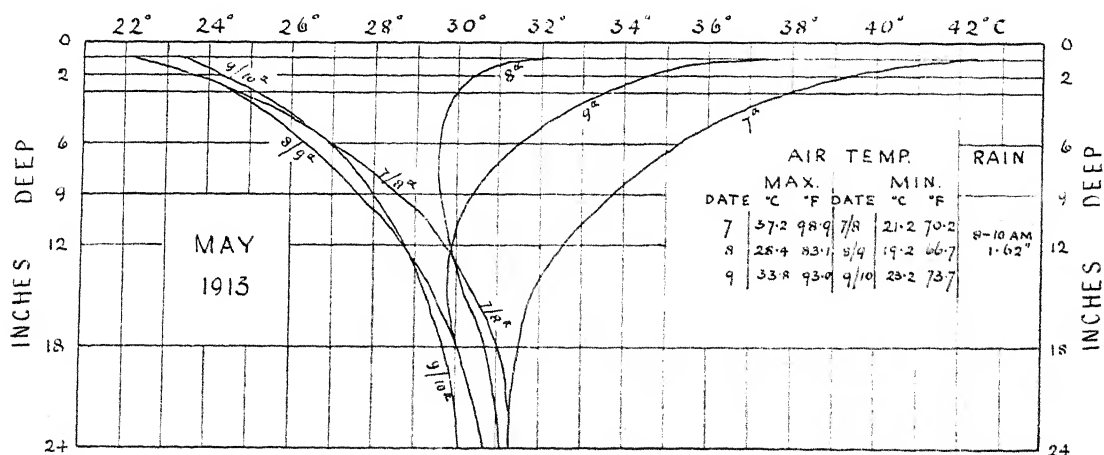
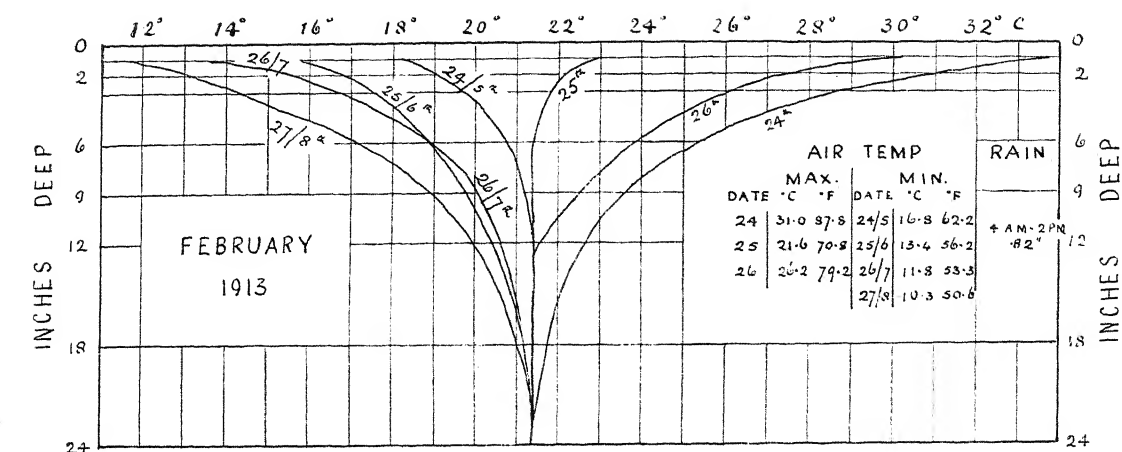
as the same soil when dry. The question has not been directly investigated here, but an examination of the contents of Table IV reveals the fact that the effect of the very great increase in soil-moisture during the monsoon on the maxima and minima is actually so slight that it cannot be detected. If, for example, the Pusa soil when wet does not rise to as high a temperature as it would do when dry, then the difference between the air and soil maxima should be smaller when the soil is wet than when dry. This is not the case; this difference was, during the two years of the records, actually somewhat greater during the monsoon period June to September than during the hot weather March to May. The influence of soil-moisture (excluding the case of odd showers or storms in the dry-season, which is specially dealt with subsequently), seems to be so slight that the relation between the soil- and the air- temperature remains practically the same during the hot weather and rains respectively.

The effect of rain.—The effect of rain on the soil-temperature will depend chiefly on two factors, (i) a sudden change of air-temperature and (ii) whether the additional water materially affects the proportion of this constituent which is already present in the soil.

Reasons have been advanced in the preceding paragraph for concluding that a change in the sp. ht. of the soil, caused by increased moisture, does not of itself affect the maximum or minimum temperature. Any marked effects of rainfalls that may be observed must therefore be referred rather to increase of evaporation and to sudden change of air-temperature than to change of sp. ht. of the soil.

In the dry season any material rainfall will cause a great change in the amount of soil-moisture, and the amount of moisture evaporating will largely increase. Such rainfalls are also always accompanied by a considerable fall of air temperature. On the other hand, during the rains, after the monsoon has become well established, the soil is thoroughly wet, and contains often





EFFECTS OF RAIN.

as much water as it will hold. A rainfall at this time will thus only alter the rate of evaporation in a minor degree. Such rainfalls are also not usually accompanied by any great change in air-temperature. It follows then that the effect of a rainfall during the dry season may be expected to influence the soil-temperature to a much greater degree than one during the monsoon. As examples of the former three instances may be considered, which are illustrated by the charts in Plate VI. The first example is of a rainfall which occurred on February 25th, 1913. The reader should note the position of the maximum curve for 24th and the minimum curve for the night 24th-25th. Rain, 0.82", fell from about 4 A.M. to 2 P.M. on 25th accompanied by a drop in maximum air-temperature from 31° to 21° C. The first result was a drop in maximum soil-temperature from 34° to 23° C at 1" deep—but on the day following the maximum at 1" deep rose again to 30° C. The minimum temperature, however, fell successively for three nights—the total fall in minimum temperature being from 18° to 12° C. These effects extended to 18" deep, but did not alter the temperature at 24". The second example is taken in May 1913. On May 8th there was a heavy rainfall—1.62"—between 8 and 10 A.M. accompanied by a drop in maximum air-temperature from 37° on 7th to 28° C on 8th. At the same time the maximum soil-temperature at 1" decreased from 42° C on 7th to 32° C on 8th, but it recovered again on 9th to 38° C. During the three nights 7th-8th to 9th-10th the minimum soil-temperature at the surface did not fall as in the February instance, nor did the minimum air-temperature change very much, but there was a fall of 1.5° C at 24" during the 72 hours. The third instance is taken from June when 5.25" fell on 24th-25th and 0.66" on 25th-26th. The maximum air-temperature dropped from 35° on 24th to 27° on 25th and that of the soil from 40° to 29° C which was however followed by a rise on 26th to 39° C. The minimum air-temperature fell from 26° to 23° C and that of the soil from 27° to 25° C. The effect of this rainfall was also perceptible at 24" deep.

The effect of rain storms is thus much more marked on the maximum soil-temperatures than on the minima, and equals approximately the fall of air-temperature, but the effect on the minima is more persistent.

THE TEMPERATURE OF CROPPED LAND.

Oats were grown on the ground above the thermometers during the cold weather of 1913-14 and san hemp (*Crotalaria juncea*) during the monsoon 1914. The oat crop was a poor one, probably because it had not been possible to cultivate this soil very well, but the san hemp grew quite normally.

The following data illustrate the protective effect of such crops :—

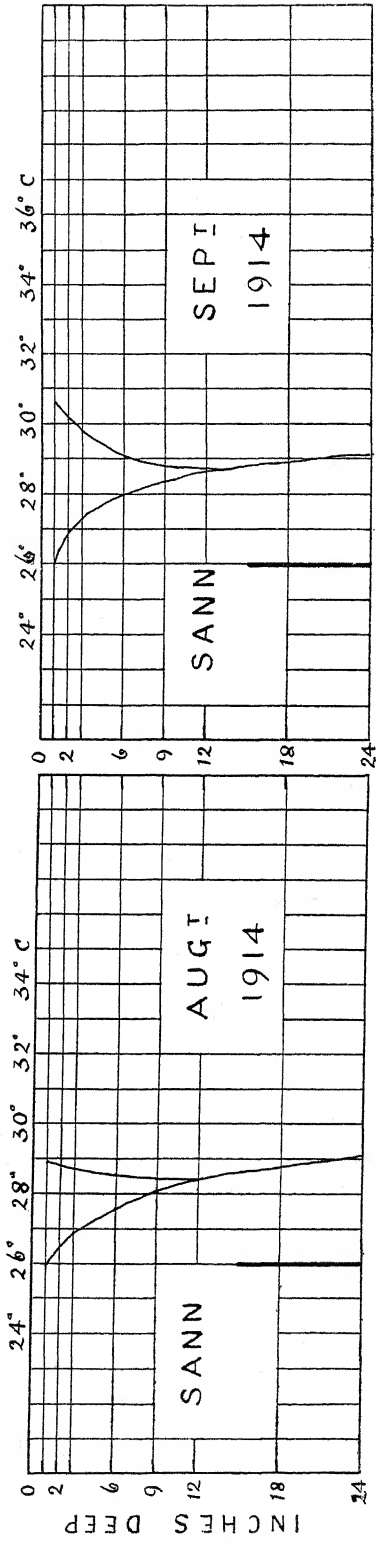
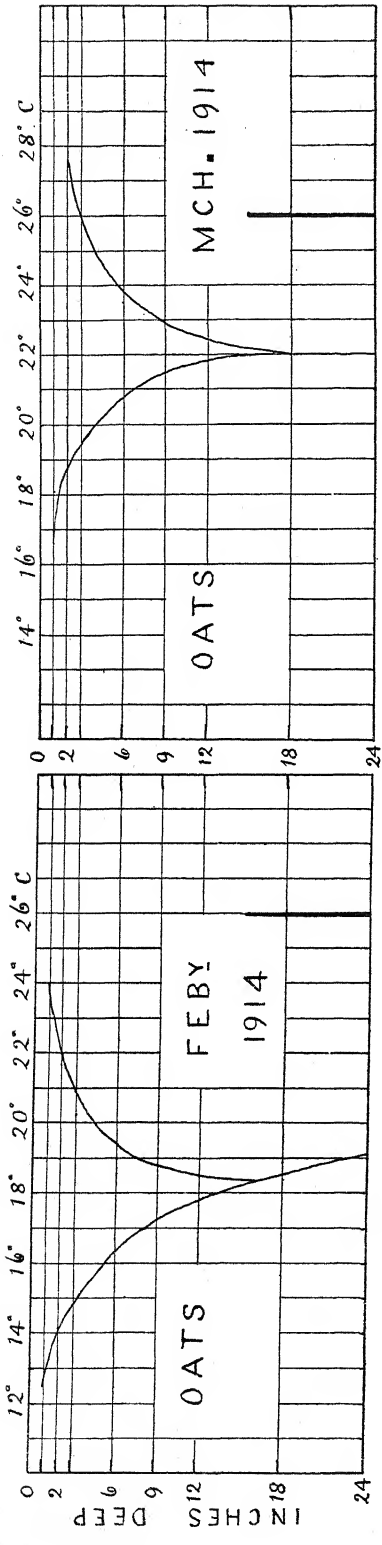
TABLE VI.

Comparison of air and cropped-soil temperatures.

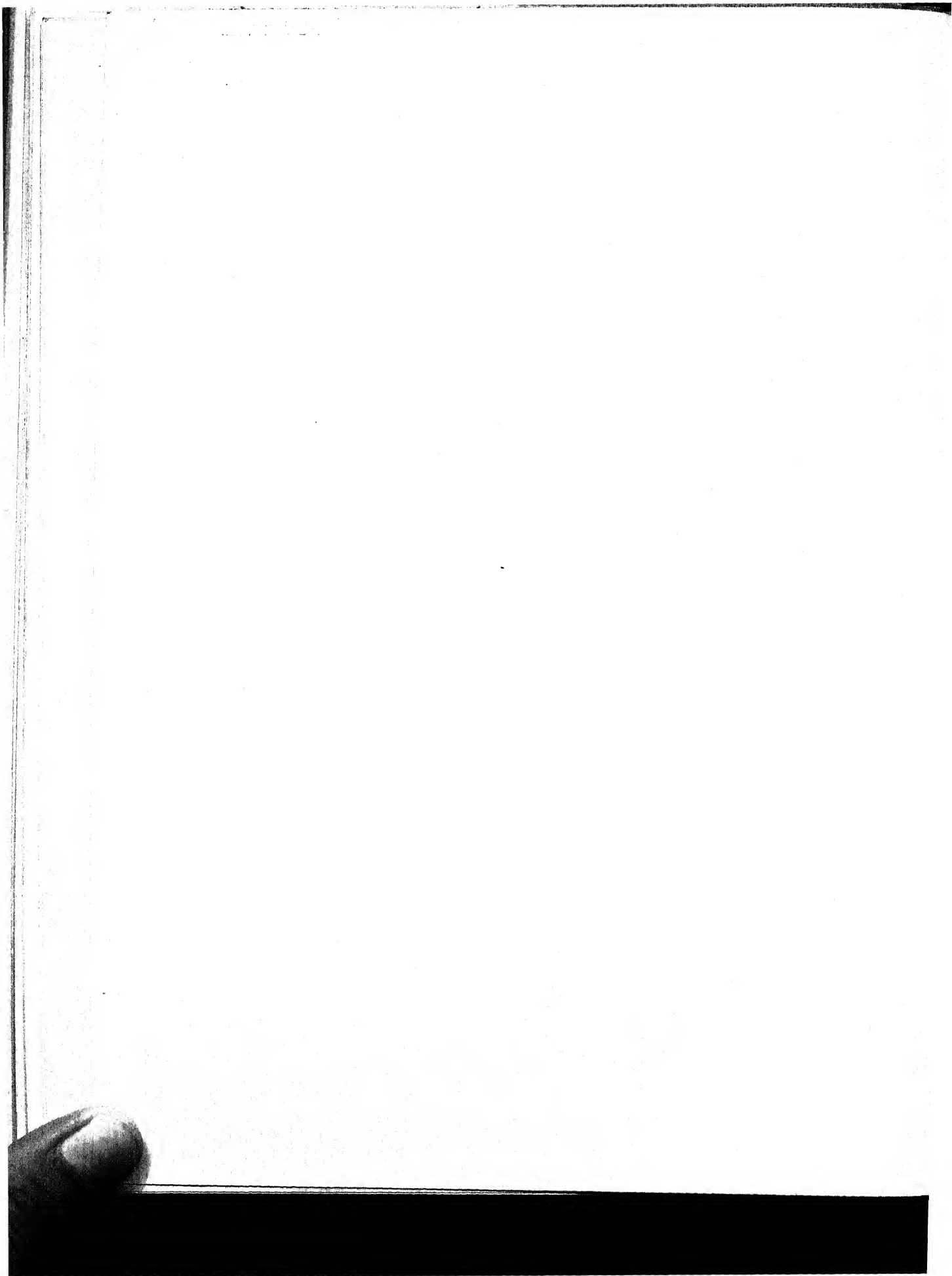
Crop.	Month.	MINIMUM.		MAXIMUM.		DIURNAL CHANGE.	
		Air.	Soil 1" deep.	Air.	Soil 1" deep.	Air.	Soil.
Oat crop ..	February ..	11.5	12.5	26.3	24.0	14.8	11.5
	March ..	15.0	16.6	31.2	29.6	16.2	13.0
San Hemp ..	August ..	25.2	25.9	31.6	28.9	6.4	3.0
	September ..	25.0	26.0	32.8	30.6	7.8	4.6

If these data are compared with those of Table IV (p. 40) it will be seen that the following characteristic differences occur :—

- (i) The maximum temperature of the soil at 1" deep does not rise so high as the air in the shade; it is less by about 2° C whereas bare fallow soil at 1" deep suffers a higher maximum by some 2° to 4° C.
- i) The minimum temperature of the soil at 1" deep is higher than that of the air, but the difference is not so great as when the soil is fallow.



CROPPED LAND.



- (iii) The diurnal change of soil temperature at 1" deep is very much smaller than when the soil is fallow ; it is only about two-thirds as great in February and March and is only about one-third as great in August and September.
- (iv) By a comparison of the charts in Plate VIII with those in Plates II and III it will be seen that the curves of maximum temperature are steeper, especially during the rains, thus shewing how much less the surface of the soil is heated when protected by a crop. In February and March the difference of temperature between 1" and the surface is probably not more than about 5° and during August and September the difference is only about 1° .

SUMMARY.

1. The temperature of the surface soil naturally varies both with the hour of the day and with the season.
2. The *seasonal* variation. The minima are in January and the maxima in May.

In bare-fallow soil.

3. The *diurnal* change of temperature extends to between 12" and 24" from the surface on most days in the year. At 12" it amounts to about 1° C, but at 24" it is doubtful whether it ever exceeds 0.1° C in Bihar and probably does not exceed 0.2° C in any part of India.
4. There is a fairly close correspondence between the temperature of *bare-fallow soil* at 1" from the surface and that of the *air in the shade* ; approximately the soil minimum at this depth is about 2.0° C higher than the air minimum, and the soil maximum is about 3.0° C higher than the air maximum.

5. There is also a similarly close relation between the *diurnal change* of temperature in the *soil* (bare-fallow) at 1" from the surface and in the *air* (shade), the diurnal change being about 1.5°C greater in the soil at this depth than in the air. This *diurnal change* is least during the monsoon and greatest during the dry season ; at the former season (June to September) it is about 10°C in the soil (bare-fallow) at 1" deep, and during the latter (in March and April) it frequently approaches 20°C .

6. The temperature of the soil near the surface (down to 3" or 4") is above the mean temperature for only about 8 hours daily, whilst it is below it for about 16 hours.

7. The *lag* in temperature is about 2 hours at 3" deep and about 8 hours at 18" from the surface.

8. A change in the sp. ht. of the soil, due to change of moisture content, does not seem to affect the maxima or minima : but rain-falls during the dry season, causing a considerable change in the amount of water evaporating, have a marked effect.

9. It is possible to estimate approximately the temperature to which the soil rises under specified conditions in other parts of India.

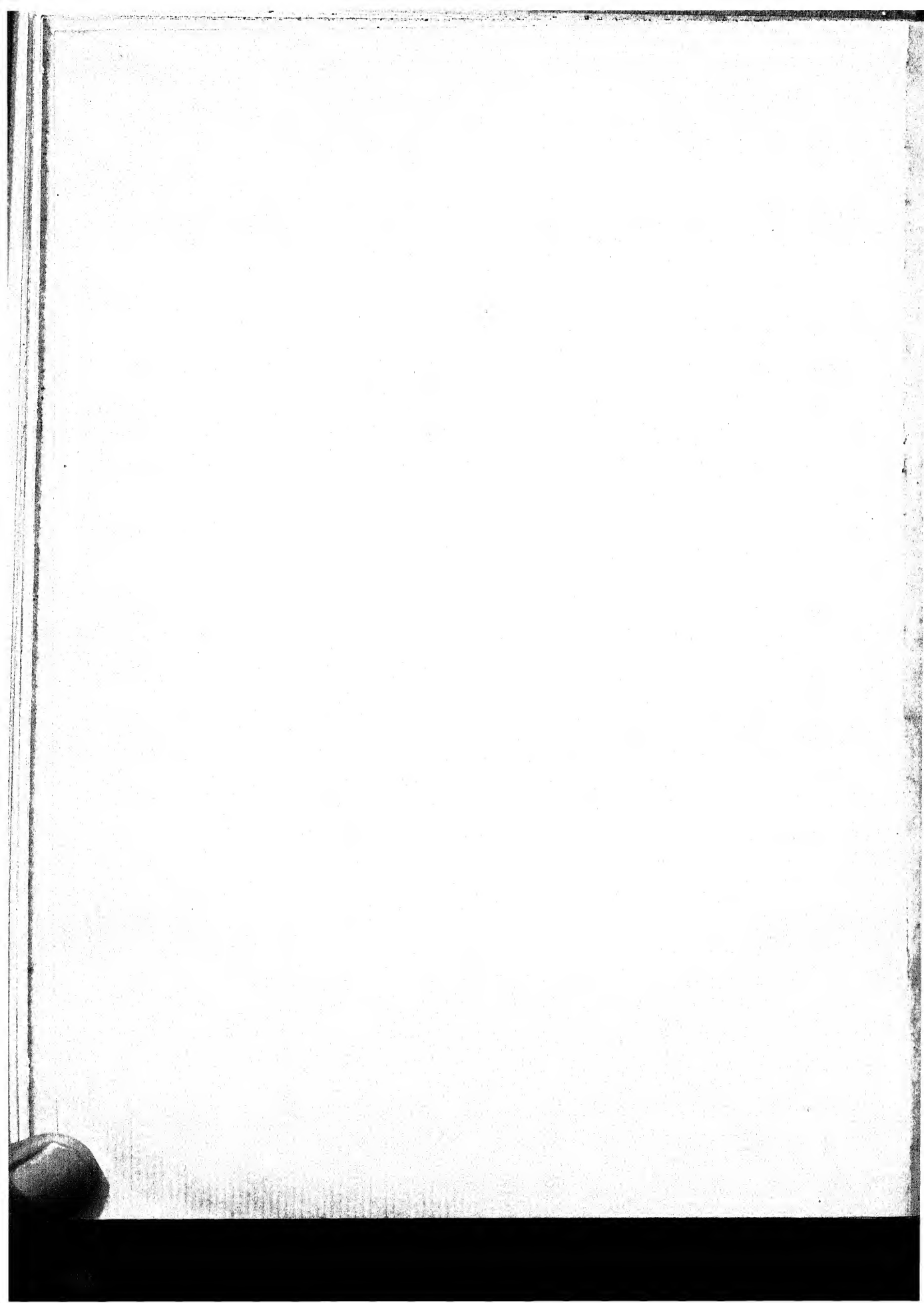
In cropped land.

10. The effect of a covering crop on the soil-temperature is naturally very marked, for it both prevents the surface soil from rising to the temperature which fallow land assumes, and also modifies the diurnal change. Thus whilst the temperature of exposed soil at 1" deep rises to about 3°C above that of the air, that of cropped land is about 2°C below it ; and whilst the temperature of exposed soil at the surface rises to probably some 20°C above that of the air, the corresponding figure for cropped land is only some 2° or 3°C even in March, whilst in the rains it is actually lower than that of the air. Also in respect of diurnal change ; at 1" deep, whilst exposed soil suffers a change

of some 20° C in March, that of cropped land is only about 13° C at the same depth ; and during the monsoon whilst exposed soil suffers a diurnal change of some 10° C at 1 " deep, that of cropped land is only about 3° to 4° C.

PUSA

November 21st, 1914.



APPENDIX.

DETAILED RECORD OF SOIL TEMPERATURES AT PUSA.

December 1911 to October 1914.

January 1912.

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.															
		Max.	Min.	Maximum.						Minimum.									
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
1	..	23.2	8.3	24.6	22.0	20.5	18.0	17.5	16.1	17.4	18.0	9.3	10.5	11.2	13.7	15.4	16.0	16.9	17.7
2	..	22.9	8.1	24.2	21.8	20.4	18.0	17.6	16.2	17.4	18.0	9.3	10.5	11.2	13.7	15.4	15.9	17.1	17.7
3	..	23.7	8.6	24.6	22.0	20.6	18.2	17.7	16.3	17.5	17.9	10.1	11.1	11.9	14.2	15.7	16.1	17.1	17.8
4	..	23.8	10.2	24.8	22.4	20.9	18.3	18.0	16.5	17.5	18.0	10.4	11.4	12.1	14.4	15.9	16.2	17.2	17.8
5	..	24.2	9.6	24.9	22.6	21.2	18.7	18.1	16.6	17.7	18.0	10.3	11.4	12.1	14.5	16.0	16.5	17.3	18.0
6	..	24.3	9.9	25.0	22.6	21.2	18.8	18.2	16.7	17.7	18.1	10.4	11.5	12.2	14.5	16.1	16.5	17.4	17.8
7	..	24.4	9.1	24.9	22.5	21.0	18.6	18.2	16.7	17.8	18.2	10.0	11.1	11.9	14.2	15.9	16.5	17.5	17.9
8	..	24.4	9.7	25.2	22.8	21.3	18.7	18.2	16.7	17.7	18.3	10.0	11.2	12.0	14.3	16.0	16.5	17.6	17.9
9	..	24.1	8.8	25.2	22.8	21.3	18.7	18.3	16.7	17.8	18.3	10.3	11.4	12.2	14.5	16.1	16.5	17.5	18.0
10	..	23.7	10.9	24.7	22.4	21.0	18.7	18.2	16.7	17.8	18.4	12.0	12.8	13.3	15.2	16.5	16.5	17.5	18.0
11	0.13	20.3	9.5	19.4	18.2	17.7	16.9	17.1	16.5	17.8	18.2	10.7	11.7	12.4	14.5	15.9	16.3	17.2	17.9
12	..	23.0	10.4	26.3	23.2	21.6	18.9	18.4	17.0	17.8	18.2	12.3	13.2	13.7	15.5	16.7	16.5	17.3	18.1
13	..	21.6	9.9	25.0	22.7	21.2	18.9	18.5	17.0	18.0	18.4	11.3	12.4	13.0	15.0	16.5	16.7	17.6	18.1
14	..	22.0	9.5	25.3	22.9	21.6	19.2	18.6	16.8	18.1	18.5	11.0	12.1	12.7	14.7	16.4	16.7	17.6	18.2
15	..	21.7	9.2	25.6	23.0	21.5	18.7	18.3	17.1	18.1	18.5	11.5	12.7	13.4	15.4	16.9	16.9	17.7	18.2
16	..	19.3	6.7	24.0	21.7	20.6	18.6	18.4	16.6	18.1	18.5	9.5	10.7	11.6	14.1	15.9	16.5	17.5	18.3
17	..	21.6	8.3	25.5	22.8	21.3	18.7	18.2	16.6	18.0	18.4	9.5	10.6	11.5	14.0	15.5	16.4	17.3	18.2
18	..	23.3	7.2	25.9	23.2	21.8	18.8	18.3	16.7	18.0	18.4	9.4	10.6	11.6	14.1	15.5	16.6	17.4	18.2
19	..	23.7	9.3	26.0	23.3	21.8	18.9	18.5	16.8	18.0	18.4	10.1	11.3	12.1	14.5	15.9	16.7	17.6	18.2
20	..	24.3	8.0	25.3	23.0	21.5	18.9	18.5	16.9	18.0	18.4	10.0	11.1	11.8	14.3	15.9	16.6	17.6	17.9
21	..	22.7	7.5	25.9	23.3	21.8	19.1	18.6	17.0	18.0	18.4	10.1	11.3	12.1	14.5	16.0	16.3	17.4	18.1
22	..	23.4	9.5	26.5	23.8	22.2	19.3	18.7	17.2	18.1	18.4	11.5	12.2	12.8	14.5	16.1	16.7	17.6	18.0
23	..	24.8	11.2	26.9	24.2	22.7	19.8	19.2	17.7	18.3	18.5	12.5	13.4	14.1	16.0	16.7	17.4	17.8	18.0
24	..	26.2	11.4	26.7	24.1	22.6	20.2	19.6	18.0	18.6	18.8	11.6	12.6	13.5	15.9	16.9	17.6	18.2	18.4
25	..	24.4	10.7	27.1	24.7	23.1	20.3	19.8	17.8	18.8	19.0	11.2	12.2	13.2	15.6	16.6	17.7	18.4	18.5
26	..	24.0	9.4	26.7	24.1	22.4	20.0	19.5	18.0	18.7	19.0	11.1	11.8	12.7	15.2	16.5	17.5	18.5	18.9
27	..	21.7	8.6	26.1	23.5	22.1	19.6	19.1	17.3	18.7	19.0	12.0	12.8	13.8	15.1	16.2	17.3	18.7	18.7
28	..	23.2	9.7	26.9	23.7	22.1	19.8	19.2	17.5	18.5	18.8	11.3	12.4	13.2	15.4	16.5	17.5	18.7	18.7
29	..	24.1	11.7	26.5	24.0	22.4	19.9	19.3	17.6	18.6	18.8	12.4	13.4	14.0	15.9	16.1	17.4	18.7	18.7
30	..	25.0	12.8	27.7	24.9	23.2	20.4	18.8	18.2	18.7	18.9	13.4	14.1	14.7	16.7	17.1	17.7	18.7	18.8
31	..	23.6	13.0	28.8	26.1	24.3	21.4	20.6	19.8	19.2	19.6	14.0	14.8	15.6	17.3	17.9	18.4	18.7	18.8
Mean	23.3	9.6	25.6	23.0	21.6	19.1	18.6	17.1	18.1	18.5	10.9	11.9	12.7	14.9	16.2	16.8	17.5	18.2

February 1912.

Date.	Rain inches.	Air (SHADE).		SOIL TEMPERATURE.														
		Max.	Min.	Maximum.							Minimum.							
				1°	2°	3°	6"	9"	12"	18"	24"	1°	2°	3°	6"	9"	12"	18"	24"
1	..	26.6	15.0	28.5	25.7	23.8	21.6	20.9	19.5	19.5	16.2	16.8	17.4	18.7	..	18.9	..	19.2
2	0.11	27.4	14.9	29.8	26.7	24.8	22.4	21.6	20.1	20.0	16.3	17.0	17.5	18.8	18.9	19.7	..	19.6
3	..	25.3	11.6	29.4	26.8	24.9	22.4	21.8	20.5	20.1	13.2	14.3	15.2	17.5	18.1	19.6	..	20.0
4	..	25.1	9.6	28.5	26.1	24.5	22.0	21.4	20.3	20.2	11.4	12.6	13.6	16.4	17.0	19.0	..	20.3
5	..	24.8	8.0	28.3	25.6	23.8	21.6	20.7	19.8	20.2	10.6	11.9	13.0	15.7	16.6	18.5	..	19.9
6	..	25.3	9.5	28.6	25.8	23.9	21.1	20.5	19.0	19.9	11.6	12.7	13.7	16.1	16.9	18.5	..	19.8
7	..	25.8	8.4	29.1	26.3	24.4	21.4	20.7	19.1	19.7	11.2	12.5	13.4	16.1	16.8	18.3	..	19.6
8	..	25.3	10.6	29.0	26.0	24.0	21.3	20.7	19.6	19.6	12.2	13.2	14.2	16.4	17.0	18.5	..	19.7
9	..	24.7	13.0	24.9	22.6	21.4	19.9	19.7	17.9	19.6	14.4	15.0	15.7	17.3	17.5	18.6	..	19.7
10	..	25.9	12.2	29.7	26.4	24.3	21.7	21.1	19.2	19.9	14.0	14.9	15.7	17.4	17.7	19.2	..	19.7
11	..	26.1	10.2	30.4	27.1	25.1	22.3	21.6	19.5	20.2	12.1	13.4	14.4	17.0	17.9	19.2	..	20.2
12	..	26.5	11.9	29.8	27.0	25.0	22.3	21.5	19.5	20.3	12.5	13.6	14.7	17.1	17.6	19.1	..	20.2
13	..	26.8	9.9	29.6	26.8	24.7	22.3	21.5	19.3	20.4	11.8	13.0	14.2	16.7	17.5	19.2	..	20.3
14	..	26.5	9.6	30.3	27.2	25.1	22.6	21.6	19.5	20.4	11.9	13.1	14.1	16.6	17.5	19.1	..	20.3
15	..	27.2	10.9	30.4	27.4	25.2	22.3	21.6	19.6	20.4	13.1	14.1	15.0	17.3	18.0	19.5	..	20.3
16	..	28.2	11.4	31.2	28.2	26.0	23.1	22.1	20.9	20.6	13.0	14.0	15.2	17.5	18.2	19.7	..	20.3
17	..	28.0	12.4	32.1	28.9	26.4	23.5	22.5	20.9	20.7	13.6	14.5	15.4	18.1	18.4	20.1	..	20.5
18	..	29.2	13.4	32.0	28.9	26.5	23.6	22.7	21.4	21.1	13.8	15.0	16.0	18.4	18.6	20.0	..	20.5
19	..	29.5	12.2	32.5	29.5	27.0	24.1	23.1	21.7	21.3	13.5	14.9	15.9	18.4	18.9	20.3	..	20.7
20	..	29.6	11.1	32.3	29.3	26.9	24.2	23.1	21.7	21.5	13.4	14.5	15.6	18.2	19.9	20.5	..	21.2
21	..	26.7	11.7	31.8	28.6	26.5	23.7	22.9	21.7	21.5	13.8	15.0	15.9	18.5	19.1	20.6	..	21.1
22	..	28.4	13.7	32.2	29.5	26.8	24.3	23.2	21.8	21.8	14.7	15.7	16.7	19.0	19.1	20.7	..	21.1
23	..	28.3	13.3	32.4	29.2	26.9	24.5	23.5	21.8	22.0	15.1	16.2	17.1	19.3	19.7	21.1	..	21.3
24	..	29.7	13.0	33.4	30.3	27.6	24.9	23.8	21.8	22.4	16.8	17.7	18.5	20.1	20.7	21.2	..	21.4
25	..	30.9	15.6	34.1	30.8	28.3	25.4	24.6	22.4	22.2	17.5	18.4	19.1	20.6	20.7	21.7	..	21.7
26	..	30.3	12.4	33.1	30.7	27.9	25.7	24.6	23.2	22.5	13.6	14.9	16.2	19.1	20.6	21.6	..	21.7
27	..	28.2	12.0	32.3	29.3	26.7	24.6	23.7	22.2	22.5	13.7	15.1	16.3	19.0	19.8	21.4	..	22.2
28	..	28.8	9.6	33.7	30.5	27.9	25.2	24.1	22.2	22.4	13.0	14.3	15.5	18.5	19.6	21.1	..	22.2
29	..	29.4	11.6	33.3	30.2	27.7	25.1	24.0	22.2	22.6	13.5	14.6	16.3	19.0	19.7	21.2	..	22.1
Mean..	..	27.3	11.7	30.8	27.8	25.7	23.1	22.2	20.6	20.9	13.4	14.5	15.5	17.5	18.4	19.9	..	20.6

March 1912.

Date.	Rain inches.	SOIL TEMPERATURE.																		
		AIR (SHADE).		Maximum.							Minimum.									
		Max.	Min.	1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"	
1	..	30.6	11.7	33.9	30.7	28.0	25.3	24.1	22.3	22.3	22.2	13.1	14.4	15.8	18.8	19.6	21.2	..	22.2	
2	..	30.3	10.7	34.1	30.9	28.2	25.2	24.1	22.3	22.3	22.2	13.1	14.5	15.6	18.7	19.2	21.3	..	22.0	
3	..	31.7	12.1	35.1	31.7	28.8	25.6	24.4	22.4	22.3	22.4	14.6	15.5	16.8	19.2	19.9	21.2	..	22.2	
4	..	32.2	12.2	35.4	32.0	29.3	25.9	24.7	23.1	22.6	22.5	14.7	15.9	16.9	19.7	20.0	21.4	..	22.2	
5	..	31.1	9.6	34.6	31.5	28.8	26.0	24.7	23.2	22.7	22.5	12.1	13.6	15.1	18.3	19.7	21.2	..	22.3	
6	..	32.0	10.2	34.3	31.0	28.9	25.3	24.2	22.5	22.6	22.8	13.1	14.3	15.6	18.9	19.8	21.2	..	22.3	
7	..	29.9	9.6	35.1	31.6	30.0	25.8	24.5	22.5	22.7	22.5	12.9	14.4	15.6	18.6	19.9	21.5	..	22.5	
8	..	31.0	12.4	35.4	32.0	30.1	25.9	24.6	22.5	22.6	22.8	14.5	15.8	16.8	19.5	20.1	21.4	..	22.2	
9	..	32.2	12.0	35.6	32.3	30.3	26.3	25.0	23.5	23.2	22.9	14.9	16.0	17.1	19.9	20.5	21.8	..	22.5	
10	..	31.6	10.9	35.9	32.7	30.8	26.6	25.4	23.6	22.9	22.9	14.2	15.7	16.9	19.9	20.9	22.1	..	22.7	
11	..	31.6	12.4	36.1	32.9	30.8	26.8	25.4	23.6	23.1	22.8	14.1	15.5	16.8	19.8	20.8	22.2	..	22.7	
12	..	32.8	15.9	36.0	32.8	30.8	26.7	25.5	23.6	23.3	22.9	15.6	16.8	17.8	20.5	20.9	22.3	..	23.0	
13	..	33.9	14.5	37.3	33.9	31.8	27.5	26.0	23.7	23.5	23.2	15.9	17.1	18.1	21.0	21.5	22.5	..	23.0	
14	..	35.6	14.3	37.5	34.1	32.2	27.9	26.4	23.9	23.8	23.7	14.7	16.3	17.6	20.6	21.7	22.9	..	23.2	
15	..	30.4	12.4	34.5	31.8	30.1	26.7	25.6	24.0	23.7	23.5	13.8	15.4	16.6	19.9	21.1	22.6	..	23.3	
16	..	31.8	14.4	35.8	32.8	30.7	26.9	25.7	23.9	23.6	23.9	14.8	16.1	17.3	20.3	21.3	22.5	..	23.3	
17	..	32.7	12.5	37.1	33.9	31.7	27.4	26.1	24.0	23.6	23.4	14.0	15.6	16.9	20.0	21.4	22.6	..	23.3	
18	..	33.6	15.9	37.3	33.9	31.9	27.5	26.1	24.0	23.8	23.5	14.4	15.8	16.9	19.9	20.9	22.5	..	23.3	
19	..	31.1	13.0	31.7	29.1	27.3	25.3	24.7	23.8	23.7	23.8	14.5	16.0	17.3	20.5	21.2	22.5	..	23.4	
20	..	33.5	11.4	37.5	34.4	32.1	27.7	26.7	24.0	23.8	23.9	14.5	16.0	17.3	20.5	21.2	22.5	..	23.3	
21	..	34.8	13.0	39.0	35.4	33.1	28.4	26.9	24.0	24.0	24.0	15.8	17.2	18.4	21.3	21.6	22.9	..	23.3	
22	..	34.2	14.6	38.4	34.8	32.4	28.3	26.9	24.3	24.4	24.6	17.0	18.2	19.3	21.8	22.2	23.4	..	23.7	
23	..	34.6	16.7	38.7	35.5	33.2	28.9	27.4	24.7	24.7	24.7	17.4	18.8	19.8	22.3	22.6	23.6	..	23.9	
24	..	35.1	15.1	39.5	36.3	33.3	29.5	28.0	25.1	24.9	25.1	17.5	19.0	20.1	22.6	23.3	24.0	..	24.2	
25	..	36.6	18.7	40.0	36.8	34.6	30.0	28.5	26.3	25.4	25.2	19.6	20.8	21.8	23.6	24.5	25.1	..	24.8	
26	..	35.3	19.2	39.4	36.3	34.5	30.2	28.7	26.4	25.7	25.5	20.5	21.5	22.2	24.3	24.2	25.1	..	24.8	
27	..	36.2	20.4	41.2	37.8	35.8	31.2	29.6	27.5	26.3	26.0	21.8	22.7	23.5	25.2	24.7	25.5	..	25.5	
28	0.55	35.6	18.5	38.5	35.3	33.7	30.6	29.3	26.7	26.5	26.6	20.6	21.9	22.6	24.5	25.0	26.0	..	25.9	
29	..	30.1	17.6	33.3	31.5	30.5	28.2	27.6	25.5	26.5	26.1	19.5	20.3	21.4	23.3	24.0	25.1	..	25.7	
30	0.25	25.4	13.5	28.5	26.8	24.9	23.6	23.0	24.0	26.0	26.5	15.7	16.7	17.7	20.4	21.5	23.3	..	24.9	
31	..	24.4	11.2	27.4	25.7	24.9	23.6	23.5	23.5	24.8	25.4	13.9	14.0	16.2	19.0	20.3	22.1	..	24.3	
Mean	32.3	13.8	35.9	32.8	30.8	27.2	26.0	24.0	23.9	23.9	15.7	16.9	18.1	20.7	21.4	22.7	..	23.4	

May 1912.

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.															
		Max.	Min.	Maximum.					Minimum.										
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
1	..	35.6	23.3	40.1	38.1	36.7	34.1	33.1	31.2	30.8	30.8	26.8	27.6	28.3	29.8	29.9	30.4	..	30.2
2	..	36.5	23.1	40.7	38.7	37.4	34.5	33.5	31.6	31.2	30.8	27.6	27.6	28.5	30.3	30.4	30.7	..	30.4
3	..	36.3	21.2	40.8	38.9	37.5	34.8	33.9	31.9	31.4	31.3	26.6	27.7	28.5	30.4	31.0	31.3	..	30.7
4	..	39.0	21.3	42.3	39.5	38.3	35.3	34.4	32.2	31.8	31.6	26.3	27.5	28.4	30.4	30.9	31.3	..	31.0
5	..	39.6	22.7	42.6	40.2	38.3	35.3	34.4	32.3	32.0	31.7	26.8	27.9	28.6	30.4	30.9	31.4	..	31.1
6	..	39.9	24.3	42.4	40.4	38.3	35.4	34.5	32.4	32.0	31.6	27.9	28.9	29.4	30.7	31.2	31.6	..	31.4
7	..	40.8	24.8	43.0	41.0	38.9	36.0	35.0	32.9	32.4	31.8	28.6	29.5	30.1	31.5	31.6	31.9	..	31.5
8	..	39.4	21.7	42.0	39.9	38.2	35.9	34.9	32.7	32.5	32.2	28.1	28.1	28.8	30.8	31.6	31.9	..	31.8
9	..	37.3	22.0	41.8	39.9	38.1	35.8	34.7	33.1	32.6	32.2	27.2	27.2	30.2	31.1	31.7	32.1	..	31.9
10	..	39.1	24.2	42.9	40.9	39.0	36.2	35.3	33.3	32.8	32.6	28.7	29.8	30.4	31.9	32.4	32.5	..	32.0
11	..	36.6	24.3	41.3	39.4	38.3	35.8	35.1	33.3	32.9	32.6	28.6	29.5	30.2	31.8	32.2	32.4	..	32.2
12	..	38.1	25.3	42.9	40.6	39.3	36.3	35.4	33.4	33.3	32.9	28.6	29.5	30.1	30.7	32.3	32.9	..	32.3
13	..	38.4	25.1	42.1	40.2	38.8	36.3	35.6	33.4	33.1	32.5	29.2	30.1	30.7	32.3	32.8	33.0	..	32.5
14	..	40.4	19.5	43.6	41.9	40.4	37.4	36.4	34.3	33.8	33.2	24.8	26.6	27.6	30.1	31.9	32.9	..	32.6
15	0.83	29.2	22.6	38.3	32.5	32.4	33.7	34.0	30.6	32.0	32.6	24.3	25.3	26.0	28.0	28.9	30.0	..	30.7
16	..	32.3	22.6	36.1	34.3	33.0	31.5	31.2	30.3	32.0	32.6	23.1	24.2	25.1	27.4	28.7	30.2	..	31.2
17	..	33.2	25.1	39.0	37.5	35.7	33.9	32.9	31.2	31.3	31.0	26.3	27.1	27.6	28.5	29.1	29.8	30.6	31.0
18	..	35.7	25.6	40.4	38.3	36.5	33.8	32.9	31.2	31.9	31.7	27.8	28.7	29.2	30.5	30.6	30.9	31.1	31.4
19	..	37.1	26.0	43.5	41.0	38.6	35.2	34.3	33.0	32.4	32.0	25.0	26.1	27.0	29.3	30.6	31.6	31.8	31.6
20	1.10	37.6	22.2	41.7	39.7	38.5	35.9	35.0	32.5	32.6	32.0	25.0	26.1	27.0	29.3	30.6	31.6	32.2	32.0
21	0.64	34.8	20.6	39.1	37.1	35.9	33.5	32.9	31.1	32.4	32.2	24.5	25.6	26.3	28.5	29.6	30.7	31.5	31.8
22	..	35.5	23.1	39.1	37.2	35.7	33.4	32.8	31.1	31.8	32.0	24.3	25.5	26.2	28.5	29.6	30.7	31.5	31.8
23	..	35.4	21.7	35.9	34.7	33.9	32.1	31.8	30.5	31.5	31.6	23.5	24.7	25.8	27.8	29.0	30.3	31.0	31.4
24	..	34.4	24.0	36.0	34.5	33.8	32.0	31.4	30.4	31.1	31.8	25.3	26.2	26.8	28.5	29.1	30.0	30.7	31.2
25	..	37.2	24.7	40.9	38.6	37.1	34.5	33.0	31.4	31.8	31.4	26.1	27.0	27.8	29.3	29.7	30.2	30.8	31.2
26	..	36.8	22.8	41.4	39.5	38.0	34.8	33.8	31.4	31.9	31.8	25.5	26.4	27.1	29.3	30.2	31.0	31.4	31.4
27	0.57	33.7	25.5	37.0	34.8	34.0	32.7	32.2	31.0	31.7	31.8	25.9	26.8	27.3	29.0	30.0	30.8	31.5	31.6
28	..	37.0	24.2	39.6	37.7	36.6	34.4	33.0	31.6	31.7	32.0	25.4	26.5	27.1	29.2	30.3	30.8	31.2	31.6
29	..	35.9	25.1	41.1	39.1	37.6	34.4	33.6	31.9	32.0	31.8	26.5	27.5	28.3	29.9	30.4	31.0	31.5	31.7
30	..	37.3	25.6	41.5	39.7	38.2	35.6	34.4	32.8	32.4	32.1	28.9	29.7	30.2	30.6	31.1	31.5	31.5	31.7
31
Mean	36.7	23.6	40.5	38.5	37.1	34.7	33.8	32.0	32.1	31.9	26.6	27.6	28.3	30.0	30.6	31.2	31.2	31.5

June 1912.

Date.	Rain inches.	SOIL TEMPERATURE.																	Air (SHADE).	Max.	Min.
		Maximum.								Minimum.											
		1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"				
1	..	39.1	26.2	43.0	41.0	39.5	36.4	35.5	33.8	33.1	32.4	29.7	30.4	31.0	31.9	32.1	32.7	32.6	32.2	32.7	
2	0.99	39.1	20.4	43.2	41.2	39.8	36.8	35.9	33.0	33.5	33.3	25.5	26.7	27.7	30.0	31.7	32.6	32.4	32.7	32.5	
3	..	35.0	25.8	38.4	36.7	35.8	34.1	33.5	32.3	33.2	33.4	26.1	28.1	28.7	30.2	31.5	32.0	32.6	32.7	32.5	
4	0.03	36.6	24.5	39.0	37.8	36.8	34.5	33.7	32.3	32.7	32.9	26.3	27.2	28.0	30.1	31.4	31.9	32.2	32.5	32.3	
5	0.75	33.7	19.4	37.8	36.3	35.4	33.7	33.0	31.4	32.5	32.5	25.0	26.7	27.3	28.2	29.9	31.0	31.4	31.9	31.8	
6	..	32.6	22.2	36.7	35.5	34.7	32.7	32.1	31.0	31.5	32.1	25.8	26.7	27.3	28.9	30.1	30.7	31.4	31.8	31.8	
7	0.09	32.7	21.7	36.5	34.9	34.0	32.7	32.1	31.8	30.5	32.1	24.9	26.0	26.7	28.4	29.9	30.6	31.3	31.4	..	
8	..	32.7	22.7	36.5	34.9	34.0	32.7	32.1	31.8	30.5	32.1	24.9	26.0	26.7	28.4	29.9	30.6	31.3	31.4	..	
9	0.80	34.9	19.3	40.4	38.8	37.2	34.6	33.1	31.5	31.7	31.4	23.5	24.7	25.6	28.2	29.6	30.4	31.1	31.2	31.3	
10	0.05	29.8	20.6	35.3	33.6	32.8	31.7	31.2	30.1	31.5	31.6	24.1	25.0	25.7	27.8	29.0	29.8	30.7	31.1	31.2	
11	..	32.7	24.8	35.8	34.1	33.0	32.0	31.1	30.5	30.9	31.7	26.8	27.6	28.1	29.5	29.1	29.7	30.5	30.8	30.8	
12	..	35.3	25.7	39.4	37.4	35.2	33.5	32.4	31.9	31.8	31.5	26.7	27.6	28.1	29.7	29.9	30.0	30.6	31.0	31.0	
13	..	37.4	26.6	41.0	39.6	38.2	35.2	33.6	31.9	31.8	31.8	28.5	29.2	29.9	30.9	30.6	30.8	31.5	31.1	31.1	
14	..	39.1	26.6	43.0	40.0	39.4	36.2	35.1	33.4	32.7	32.3	29.7	30.6	30.9	30.9	30.6	30.8	31.5	31.1	31.5	
15	..	40.4	27.6	43.1	41.3	40.0	37.0	36.1	34.0	33.5	32.9	30.7	31.4	31.7	32.2	32.2	31.9	32.7	32.3	32.3	
16	..	40.9	26.9	44.4	42.5	41.2	37.8	36.9	34.9	34.3	33.6	31.4	32.0	32.4	33.5	33.9	33.7	34.2	33.9	33.9	
17	..	39.5	27.7	44.7	42.7	41.5	38.3	37.5	35.6	34.7	34.1	31.5	32.2	32.7	34.0	34.8	34.3	34.9	34.2	33.7	
18	..	38.3	27.4	43.5	41.7	40.6	38.0	37.3	35.4	35.1	34.9	31.6	32.3	32.6	34.1	35.0	34.9	34.9	34.7	34.2	
19	..	35.9	26.0	43.4	41.6	40.5	38.1	37.4	35.4	35.1	34.9	31.6	32.3	32.6	34.1	35.0	34.9	34.9	34.3	34.3	
20	..	37.6	26.8	43.6	41.7	40.6	38.0	37.3	35.4	35.1	34.9	31.6	32.3	32.6	34.1	35.0	34.9	34.9	34.3	34.3	
21	..	35.9	26.1	43.5	41.4	40.2	37.5	36.9	35.5	35.1	35.1	31.5	32.2	32.8	34.2	35.1	34.9	34.9	34.4	34.4	
22	..	37.1	27.1	43.1	41.4	40.3	37.6	36.9	35.4	34.9	34.5	31.3	32.0	32.5	33.9	34.5	34.6	34.8	34.4	34.4	
23	0.71	39.2	24.0	43.4	41.5	40.3	37.5	36.9	35.4	34.9	34.5	27.8	28.5	29.4	31.7	33.1	33.6	34.3	34.4	34.4	
24	0.59	24.8	24.8	39.0	37.3	36.1	34.6	34.0	33.2	34.5	34.8	29.1	29.5	29.4	30.9	32.1	32.4	33.0	33.3	33.6	
25	..	34.8	27.4	38.3	37.0	36.0	34.4	33.5	32.5	33.1	33.2	28.1	29.1	29.5	30.9	32.2	32.4	33.3	33.3	33.3	
26	0.13	34.9	25.8	37.9	36.3	35.2	33.7	33.0	32.5	33.4	33.5	28.4	29.2	29.5	30.9	32.1	32.4	33.0	33.3	33.6	
27	..	32.8	25.7	34.5	33.3	33.1	32.6	32.5	31.8	32.8	32.9	27.3	28.0	28.5	30.6	31.3	31.6	32.4	32.8	32.7	
28	0.83	34.7	26.9	36.7	35.4	34.5	33.9	32.8	31.8	32.5	32.5	28.2	29.2	29.5	30.6	31.6	31.7	32.3	32.5	32.5	
29	..	36.7	26.8	41.5	39.3	37.4	34.6	33.9	32.5	32.6	33.1	28.7	29.3	29.8	31.0	31.7	31.8	32.5	32.5	32.5	
30	0.33	36.0	24.7	43.3	40.3	38.5	35.0	33.8	31.9	32.6	33.3	26.8	27.6	28.1	29.8	31.2	31.7	32.3	32.6	32.6	
Mean	..	36.0	25.0	40.3	38.6	37.4	35.2	34.4	32.9	33.1	33.3	28.0	28.9	29.4	31.0	31.9	32.2	32.6	32.7	32.7	

July 1912.

Date.	Rain inches.	SOIL TEMPERATURE.																		
		AIR (SHADE).		Maximum.						Minimum.										
		Max.	Min.	1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"	
°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	
1	1.47	33.7	25.3	37.2	35.5	34.5	33.5	32.7	31.7	33.1	33.5	26.8	27.5	27.8	29.4	31.0	31.4	32.1	32.0	
2	1.08	29.4	23.9	31.5	31.1	30.9	31.6	31.3	30.9	32.1	32.9	27.1	27.6	27.7	28.7	29.6	30.2	31.3	31.7	
3	1.52	27.8	24.9	29.4	29.5	29.1	29.5	30.0	29.6	31.4	32.6	26.6	27.1	27.2	28.5	29.2	29.5	30.4	31.2	
4	0.13	31.6	25.9	34.8	32.0	32.0	30.9	30.5	30.0	30.6	31.8	27.5	27.8	28.0	28.8	29.7	29.7	30.4	30.9	
5	3.46	27.4	24.6	28.8	28.6	28.5	29.2	29.6	28.9	30.4	31.3	26.2	26.6	26.9	27.8	28.6	28.8	29.7	30.3	
6	0.48	27.4	24.9	31.7	30.6	30.0	29.2	29.1	28.6	29.6	30.2	26.4	26.7	26.8	27.7	28.5	28.6	29.3	29.8	
7	..	32.2	25.7	35.2	33.3	32.5	31.0	30.2	29.6	29.5	30.0	26.7	27.2	27.8	28.1	28.6	28.6	29.2	29.8	
8	0.30	31.9	26.0	34.3	33.1	32.4	31.4	30.4	29.8	29.8	30.3	27.2	27.8	27.9	28.6	29.3	29.1	29.6	30.0	
9	..	33.7	26.7	37.8	35.8	34.8	32.5	31.8	30.4	30.3	30.4	27.8	28.4	28.6	29.6	29.8	29.9	29.7	30.2	
10	2.21	33.6	24.1	37.3	35.5	34.6	33.0	32.1	31.0	30.8	31.0	26.7	27.3	27.7	28.6	29.3	30.3	30.3	30.3	
11	0.22	32.1	24.6	36.9	34.7	33.9	32.7	31.5	30.5	30.7	31.2	27.3	27.8	28.2	29.1	30.2	30.3	30.3	30.7	
12	0.03	28.2	24.1	30.0	29.8	29.8	30.5	29.9	29.5	30.7	31.2	26.1	26.6	27.0	28.0	29.0	30.3	30.7	30.7	
13	1.48	28.5	23.8	30.3	29.7	29.4	29.2	29.3	28.9	30.2	31.0	25.7	26.2	26.5	27.6	28.4	28.7	29.6	30.6	
14	1.10	29.3	24.5	31.9	30.3	29.7	29.0	28.8	28.5	29.6	30.6	26.3	26.7	26.9	27.5	28.3	28.5	29.1	29.6	
15	..	31.7	26.7	35.6	33.9	33.1	31.0	30.5	29.4	29.3	30.1	27.6	27.9	28.2	28.7	29.5	29.5	29.6	29.7	
16	..	34.6	25.4	38.7	36.5	35.1	32.4	31.6	30.1	30.5	30.6	26.8	27.5	27.9	28.7	29.7	30.2	30.9	30.8	
17	..	33.8	26.2	37.6	35.7	34.8	32.7	31.9	31.0	30.5	31.2	28.9	29.2	29.7	30.4	30.6	30.5	30.7	30.7	
18	..	33.7	27.0	38.2	36.3	35.4	33.2	32.6	31.5	31.0	31.6	28.2	28.8	29.0	30.1	30.9	31.0	31.2	31.2	
19	0.14	33.6	25.7	36.5	34.6	33.8	32.2	31.8	30.9	31.1	31.6	27.8	28.4	28.9	30.0	30.9	30.9	31.1	31.2	
20	..	33.2	25.8	36.3	34.6	33.9	32.1	31.5	30.6	31.1	31.6	27.3	28.0	28.1	29.4	30.4	30.5	31.0	31.0	
21	0.03	32.2	25.4	34.2	33.0	32.4	31.6	31.1	30.4	31.0	31.4	27.7	28.2	28.3	29.3	30.2	30.2	30.7	30.9	
22	0.75	31.6	25.5	34.2	33.0	32.4	31.6	31.1	30.4	31.0	31.4	28.5	29.2	29.2	30.1	30.4	30.3	30.7	30.9	
23	..	33.7	27.0	37.7	35.8	34.7	32.9	32.0	31.3	30.9	31.3	27.3	27.8	28.1	29.3	30.2	30.3	30.6	30.8	
24	..	30.2	25.8	32.2	31.6	31.3	32.0	31.6	30.6	30.9	31.3	27.2	27.6	27.9	29.1	29.9	30.0	30.3	30.4	
25	..	33.1	25.2	36.5	34.5	33.5	32.5	31.6	30.8	30.7	31.6	27.0	27.4	27.7	29.3	30.0	30.3	30.7	30.8	
26	0.06	32.1	26.0	33.7	32.5	32.0	31.5	31.0	30.5	30.6	31.5	26.9	27.3	27.7	29.6	30.4	30.4	30.5	30.7	
27	..	33.1	25.6	35.5	33.6	33.0	32.2	31.3	30.2	30.5	31.4	26.5	27.3	27.8	29.1	30.0	30.3	30.5	30.7	
28	0.02	34.3	25.5	36.4	34.9	33.5	32.9	31.9	30.7	30.7	31.4	26.5	27.3	27.8	29.6	30.4	30.3	30.5	30.7	
29	..	34.7	27.1	37.9	36.1	35.3	33.0	32.0	30.8	30.9	31.7	27.3	28.1	28.4	29.6	30.4	30.3	30.7	30.9	
30	..	33.6	26.0	37.2	35.4	34.3	33.1	31.9	30.7	30.7	31.8	27.3	27.8	28.1	29.5	30.5	30.4	30.7	30.9	
31	..	34.1	26.2	40.0	37.8	36.7	34.7	33.8	31.5	31.1	31.6	27.8	28.5	28.9	30.1	31.0	30.5	30.8	31.2	
Mean..	..	31.9	25.5	35.0	33.6	32.8	31.8	31.2	30.3	30.7	31.3	27.2	27.4	28.0	29.1	29.8	29.9	30.3	30.6	

August 1912.

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.																				
		Max.	Min.	Maximum.						Minimum.														
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"					
1	0.07	33.7	26.1	°C	38.8	36.9	35.9	°C	32.8	31.5	31.4	°C	28.1	28.7	30.3	31.4	°C	31.1	31.3	31.3	°C	31.1	31.3	31.5
2	0.05	35.8	25.8	°C	43.1	40.5	39.2	°C	35.4	34.4	32.1	°C	28.3	29.4	31.1	31.9	°C	31.3	31.3	31.8	°C	31.3	31.3	31.5
3	0.45	34.2	25.0	°C	40.8	38.6	37.6	°C	35.1	34.1	32.4	°C	27.1	28.0	28.6	30.3	°C	31.6	32.0	31.6	°C	31.6	32.0	31.8
4	..	33.1	25.2	°C	37.5	35.4	34.5	°C	33.8	32.7	31.4	°C	27.3	28.0	28.5	29.9	°C	31.0	31.0	30.8	°C	31.7	31.7	31.9
5	0.49	32.0	25.3	°C	35.5	34.0	33.4	°C	33.2	32.1	31.4	°C	27.2	28.1	28.8	30.1	°C	31.0	30.9	30.8	°C	31.3	31.3	31.5
6	..	33.4	26.2	°C	38.2	36.2	36.0	°C	34.3	34.0	31.7	°C	27.8	28.4	28.8	30.1	°C	31.0	30.9	30.8	°C	31.2	31.2	31.5
7	..	33.4	26.3	°C	38.3	36.4	35.3	°C	33.6	32.9	31.8	°C	27.9	28.7	29.1	30.5	°C	31.1	31.3	31.4	°C	31.6	31.6	31.5
8	0.07	35.6	26.1	°C	39.4	37.7	36.5	°C	34.2	33.4	31.9	°C	26.6	27.2	27.6	29.2	°C	30.4	31.4	31.4	°C	31.6	31.6	31.5
9	0.07	32.6	24.9	°C	34.7	33.5	32.9	°C	32.3	31.9	30.9	°C	27.8	28.4	28.7	30.4	°C	30.4	31.4	31.4	°C	31.6	31.6	31.5
10	0.52	31.2	25.1	°C	35.3	33.4	32.8	°C	31.8	31.4	30.9	°C	27.1	27.5	28.0	29.9	°C	30.4	30.2	30.2	°C	31.2	31.2	31.5
11	0.94	32.2	25.2	°C	37.6	35.4	34.3	°C	33.8	31.9	30.9	°C	27.3	27.9	28.1	29.1	°C	30.2	30.5	30.9	°C	30.9	30.9	31.3
12	0.28	32.7	25.2	°C	36.7	34.8	34.0	°C	33.3	31.7	30.7	°C	27.4	28.6	28.7	29.4	°C	30.0	30.6	30.6	°C	30.9	30.9	31.2
13	0.10	32.6	26.0	°C	37.2	35.1	34.2	°C	33.5	31.9	31.1	°C	28.3	28.8	29.1	30.1	°C	30.8	30.8	30.8	°C	31.0	31.0	31.1
14	..	31.5	26.0	°C	36.3	34.2	33.5	°C	32.0	31.7	31.3	°C	28.2	28.7	29.0	30.0	°C	30.9	30.6	30.9	°C	31.0	31.0	31.1
15	0.05	32.6	26.1	°C	36.6	34.5	33.5	°C	33.5	31.7	31.4	°C	27.8	28.3	28.6	29.7	°C	31.0	30.4	30.4	°C	30.5	31.0	31.0
16	0.67	31.7	25.5	°C	35.3	33.6	33.0	°C	32.8	31.4	30.9	°C	28.1	28.6	28.8	29.7	°C	30.5	30.4	30.7	°C	30.7	30.9	31.0
17	0.06	33.2	26.1	°C	36.6	34.8	33.9	°C	33.2	32.0	31.3	°C	28.3	28.8	29.1	30.0	°C	30.7	30.6	30.9	°C	30.9	31.0	31.0
18	0.38	31.6	25.1	°C	33.5	32.3	31.8	°C	33.5	30.9	30.7	°C	27.3	28.0	28.2	29.3	°C	30.1	30.2	30.6	°C	30.9	31.0	31.0
19	0.37	30.4	24.6	°C	33.4	31.8	31.1	°C	30.8	30.3	30.6	°C	26.6	27.0	27.2	28.5	°C	29.2	29.5	30.2	°C	30.2	30.3	30.3
20	0.11	30.0	24.3	°C	34.7	32.8	32.0	°C	30.7	30.2	30.2	°C	27.0	27.7	27.9	28.4	°C	29.2	29.4	29.9	°C	29.9	30.1	30.3
21	1.22	31.0	25.2	°C	36.5	34.3	33.2	°C	31.3	30.2	30.2	°C	26.7	27.0	27.2	28.9	°C	29.4	29.2	29.2	°C	29.7	30.1	30.6
22	..	29.3	25.2	°C	32.1	31.4	31.0	°C	30.3	30.0	29.9	°C	26.8	27.4	27.7	28.5	°C	29.4	29.2	29.2	°C	29.7	30.1	30.6
23	..	34.4	27.1	°C	37.9	35.7	34.8	°C	31.5	30.5	30.1	°C	26.8	27.4	27.7	28.5	°C	29.4	29.2	29.2	°C	29.7	30.1	30.6
24	0.37	30.4	23.9	°C	34.7	32.9	32.1	°C	32.4	31.5	30.1	°C	26.7	27.2	27.4	28.5	°C	29.6	29.6	29.6	°C	29.8	30.1	30.3
25	0.08	30.3	24.1	°C	34.0	32.5	32.0	°C	30.4	30.4	29.9	°C	26.0	26.9	27.0	28.6	°C	29.2	29.2	29.2	°C	29.8	30.2	30.2
26	..	33.6	25.6	°C	38.7	36.4	35.3	°C	32.7	31.8	30.2	°C	27.8	28.3	28.7	29.0	°C	29.5	29.5	29.5	°C	29.8	30.2	30.2
27	0.25	34.2	25.8	°C	38.9	36.6	35.6	°C	33.0	32.2	30.7	°C	27.4	28.2	28.6	29.9	°C	30.5	30.3	30.3	°C	29.8	30.2	30.5
28	..	33.1	26.4	°C	37.7	36.0	35.0	°C	32.9	32.3	31.2	°C	27.7	28.4	28.6	30.1	°C	30.6	30.6	30.6	°C	30.6	30.8	30.8
29	..	32.6	26.2	°C	35.4	33.5	32.9	°C	31.5	30.8	30.9	°C	26.9	27.5	28.0	29.5	°C	30.4	30.4	30.4	°C	30.6	30.8	30.8
30	0.03	32.6	25.7	°C	35.0	33.5	33.0	°C	32.7	31.4	30.8	°C	26.8	27.6	28.0	29.1	°C	30.0	30.2	30.2	°C	30.6	30.8	30.8
31	..	33.1	26.7	°C	37.2	35.4	34.0	°C	33.2	31.9	31.4	°C	28.0	28.7	29.0	30.0	°C	30.6	30.2	30.2	°C	30.6	30.8	30.8
Mean..	..	32.5	25.5	°C	36.7	34.8	34.0	°C	32.7	31.9	31.0	°C	27.5	28.1	28.4	29.6	°C	30.4	30.4	30.4	°C	30.7	30.7	31.0

September 1912.

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.															
		Max.	Min.	Maximum.						Minimum.									
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
1	..	33.6	26.8	39.4	37.2	35.9	33.1	32.6	31.1	31.1	30.8	28.6	29.1	29.4	30.4	31.0	30.6	30.8	31.3
2	0.72	30.8	23.6	33.6	31.8	31.5	32.4	31.2	30.6	31.1	32.0	26.5	26.9	27.2	28.6	30.0	30.4	30.9	31.1
3	0.12	32.1	24.1	36.2	34.3	33.3	31.7	31.1	30.5	30.8	31.3	27.2	27.5	27.5	28.6	30.0	30.1	30.6	30.8
4	0.47	34.2	24.7	38.8	36.3	35.3	33.5	32.4	31.4	30.9	31.4	27.5	28.2	28.6	29.8	30.5	30.5	30.5	30.8
5	0.53	33.1	24.8	37.2	35.5	34.7	33.1	32.4	31.5	31.1	31.6	27.7	28.3	28.5	29.9	30.8	30.9	31.0	31.0
6	0.03	32.4	24.9	35.5	33.7	33.0	32.8	31.5	30.6	31.0	31.7	27.1	27.7	28.0	29.2	29.8	30.4	30.9	30.9
7	0.04	31.6	24.5	33.8	32.7	32.2	31.4	31.0	30.1	30.9	31.5	26.2	26.8	27.2	28.7	29.6	30.0	30.6	30.8
8	0.61	31.4	25.0	35.4	33.3	32.5	31.1	30.7	29.9	30.6	31.3	26.1	26.6	26.9	28.0	28.9	29.0	29.6	30.2
9	0.59	31.0	25.2	35.2	33.0	32.1	31.6	30.7	30.1	30.4	31.3	26.7	27.3	27.7	28.7	29.6	30.3	30.7	30.7
10	0.22	28.4	24.1	29.8	29.7	29.1	29.5	29.4	29.6	30.0	31.3	27.1	27.6	27.6	28.7	29.6	29.9	30.2	30.4
11	..	32.0	23.2	35.9	33.5	32.5	31.2	30.1	29.7	29.8	30.5	26.1	26.6	26.9	28.0	28.9	29.0	29.6	30.2
12	..	23.5	22.9	36.5	34.5	33.5	31.4	30.8	29.9	29.8	30.3	24.4	25.3	26.1	27.8	28.8	29.1	29.7	30.0
13	..	32.6	23.8	36.6	34.5	33.4	31.7	30.9	29.8	29.9	31.0	24.8	25.7	26.1	27.9	29.0	29.2	29.7	30.1
14	..	33.1	23.9	36.6	34.7	33.8	32.9	31.0	30.0	30.1	30.5	25.1	25.9	26.6	28.0	28.9	29.3	29.7	30.1
15	..	33.6	24.1	37.9	35.7	34.3	32.9	31.4	29.9	30.1	31.2	25.2	26.1	26.6	28.4	29.3	29.4	29.7	30.1
16	..	33.9	24.6	37.9	35.7	34.6	33.0	31.7	30.5	30.4	31.2	25.7	26.6	27.1	28.9	29.5	30.0	30.2	30.3
17	..	34.3	25.3	38.4	36.0	34.6	33.0	31.9	30.8	30.5	31.1	26.2	26.9	27.6	29.0	30.0	30.2	30.3	30.5
18	..	34.5	25.1	37.6	35.3	34.4	33.4	31.9	30.7	30.8	32.0	26.3	27.2	27.6	29.3	30.1	30.3	30.7	30.7
19	..	34.7	25.2	37.7	35.7	34.4	33.4	32.0	31.0	30.8	31.6	25.3	25.6	26.2	28.6	29.9	30.0	30.6	31.0
20	..	35.2	23.1	38.5	36.1	35.1	33.5	32.4	31.1	30.9	31.6	25.3	25.6	26.2	28.6	29.9	30.0	30.7	30.8
21	..	35.1	21.2	36.9	35.3	34.1	33.5	32.4	31.1	30.9	31.6	25.3	25.6	26.2	28.6	29.9	30.0	30.7	30.8
22	..	34.8	20.7	36.9	34.9	33.4	33.3	32.4	29.9	30.6	31.1	23.0	24.4	24.9	27.8	29.3	29.8	30.6	30.9
23	..	35.3	21.7	39.3	37.2	35.8	33.2	31.9	30.6	30.7	31.2	23.9	25.1	25.6	27.8	29.0	29.8	30.6	30.8
24	..	34.6	23.3	39.6	37.0	36.1	33.8	32.3	30.9	30.7	31.2	23.9	25.1	25.6	27.8	29.0	29.8	30.6	30.8
25	..	35.2	24.4	40.8	38.0	36.0	34.0	32.4	30.8	30.9	31.4	25.4	26.3	26.7	28.8	29.5	30.1	30.4	30.8
26	..	33.0	23.3	36.0	34.3	33.7	32.9	32.6	30.3	30.8	31.3	25.4	26.5	27.5	29.3	30.0	30.4	30.8	30.7
27	..	33.7	24.6	38.7	36.5	35.2	33.5	31.9	30.9	30.8	31.5	25.5	26.1	26.6	28.4	29.6	30.1	30.7	30.9
28	..	33.3	24.5	38.6	36.6	35.5	33.8	32.1	31.0	30.8	31.5	26.4	27.2	27.6	29.1	30.2	30.1	30.7	30.8
29	..	33.1	24.6	39.4	37.3	36.0	34.0	32.4	30.8	30.9	31.6	26.8	27.6	28.1	29.4	30.4	30.5	30.6	30.8
30	..	34.3	26.0	39.8	37.7	36.6	34.5	32.9	31.4	31.3	31.5	26.6	27.4	28.1	29.5	30.4	30.8	30.8	31.0
Mean..	..	33.2	24.1	37.1	35.1	34.1	32.8	31.7	30.5	30.7	31.3	26.0	26.8	27.2	28.8	29.8	30.0	30.4	30.7

SOIL TEMPERATURES

October 1912.

Date.	Rain inches.	AIR (SHADE)		SOIL TEMPERATURE.									
		Max.	Min.	Maximum.					Minimum.				
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"
1	0.14	35.6	26.2	40.1	38.3	37.0	34.5	33.1	31.4	31.4	31.7	27.7	28.4
2	0.02	34.3	24.7	37.1	35.5	34.5	33.9	32.4	31.5	31.4	31.8	27.2	28.0
3	..	30.4	23.0	33.0	32.0	31.6	31.7	30.9	30.7	31.4	31.8	25.0	26.5
4	..	32.3	24.1	35.7	33.8	33.2	33.2	31.3	30.4	30.9	31.6	26.3	27.2
5	..	32.7	23.9	35.2	33.3	32.7	32.6	30.9	29.8	30.7	31.3	23.7	24.8
6	..	33.4	23.2	37.3	35.3	34.3	32.4	31.1	29.8	30.4	31.3	24.7	25.7
7	..	33.6	23.8	38.1	35.6	34.4	33.3	31.4	29.9	30.4	31.3	25.3	26.2
8	..	33.1	23.8	37.6	35.6	34.6	33.0	31.4	30.4	30.4	31.2	25.3	26.5
9	..	32.1	23.5	36.3	34.2	33.4	32.5	31.2	30.2	30.4	31.3	25.3	26.1
10	..	32.8	23.3	35.5	33.4	32.5	31.2	30.9	29.7	30.4	31.1	24.5	25.7
11	..	34.5	21.1	37.1	35.2	34.2	32.5	31.1	29.8	30.3	31.2	22.8	24.1
12	..	34.8	20.5	37.8	35.6	34.4	32.0	31.1	30.0	30.3	31.3	23.3	24.4
13	..	33.9	21.7	37.3	35.0	33.8	31.9	30.8	29.4	30.2	30.8	23.4	24.2
14	..	34.5	22.0	38.0	35.5	34.3	31.9	30.9	29.7	30.1	30.7	23.6	24.7
15	..	33.9	19.0	38.0	35.7	34.5	32.9	31.1	29.7	30.9	30.6	21.4	22.8
16	..	33.2	16.9	36.0	34.0	33.0	31.1	30.1	29.3	30.1	30.7	19.7	21.1
17	..	32.8	16.2	36.0	33.4	32.3	30.5	29.4	28.5	29.4	30.8	19.5	20.6
18	..	32.7	16.8	35.7	33.2	32.3	31.4	28.8	27.4	28.4	30.3	20.2	21.3
19	..	32.1	17.8	35.5	33.2	31.9	30.9	29.9	27.9	28.4	30.3	20.2	21.3
20	..	32.1	18.1	35.9	33.0	31.7	30.9	29.9	27.6	28.3	30.2	21.3	22.4
21	..	32.4	19.4	35.9	33.5	32.3	29.5	28.8	27.8	28.0	29.6	20.7	21.9
22	..	32.6	19.0	35.9	33.6	32.4	29.5	28.9	27.4	28.1	28.9	20.7	21.9
23	..	33.0	17.0	35.4	33.1	32.0	30.4	28.5	27.1	28.0	28.9	19.8	21.0
24	..	32.6	16.8	35.4	32.8	31.5	30.9	28.1	27.1	27.9	28.9	19.4	20.6
25	..	32.2	17.1	34.6	32.2	31.1	29.9	28.1	26.4	27.4	28.8	19.2	20.4
26	..	31.9	17.3	34.1	31.8	30.7	28.6	27.5	26.3	27.4	28.1	19.3	20.5
27	..	32.0	17.3	34.1	31.9	30.7	28.0	27.4	26.2	27.1	27.6	19.3	20.4
28	..	31.4	17.4	34.5	32.0	30.9	28.0	27.4	25.9	26.9	27.8	19.4	20.5
29	..	31.4	18.8	34.9	32.2	31.1	28.5	27.6	26.1	26.9	28.0	20.3	21.2
30	..	31.4	19.0	34.1	31.7	30.6	28.2	27.4	26.0	26.8	28.2	20.8	21.5
31	..	32.8	20.2	36.1	33.9	32.8	31.2	29.9	28.6	29.3	30.2	22.2	23.3
Mean..	..	32.8	20.2	36.1	33.9	32.8	31.2	29.9	28.6	29.3	30.2	22.2	23.3

December 1912.

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.															
		Max.	Min.	Maximum.						Minimum.									
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
1	..	22.8	9.1	25.8	23.1	22.3	21.5	19.9	18.6	20.7	22.4	10.7	12.1	12.9	15.6	17.4	18.6	19.9	21.2
2	..	23.0	8.7	25.6	23.1	21.9	21.3	19.6	18.4	20.2	21.8	10.5	11.9	12.7	15.2	17.0	18.2	19.6	20.7
3	..	22.6	10.1	24.8	23.1	21.5	20.5	19.2	18.3	19.6	21.5	11.2	12.2	13.1	15.5	17.2	18.1	19.3	20.4
4	..	23.1	9.8	25.5	23.1	21.9	20.8	19.3	18.3	19.6	21.0	11.1	12.3	13.1	15.4	17.2	18.1	19.2	20.3
5	..	23.3	9.0	25.6	23.2	22.2	20.2	19.3	18.2	19.5	21.0	10.9	12.1	12.8	15.4	17.0	18.0	19.2	20.2
6	..	23.0	8.9	26.0	23.1	21.9	19.9	19.3	18.2	19.4	20.8	11.1	12.1	13.1	15.4	17.0	18.0	19.1	20.1
7	..	23.7	9.9	25.4	22.9	21.9	20.0	19.1	18.2	19.4	20.8	11.8	13.0	13.7	15.9	17.4	17.8	18.9	19.9
8	..	24.4	10.2	26.0	23.6	22.3	20.5	19.5	18.6	19.4	20.9	11.7	12.8	13.6	15.8	17.1	17.9	18.7	19.9
9	..	24.6	10.5	26.0	23.8	22.5	20.5	19.6	18.5	19.4	20.7	11.4	12.6	13.5	15.9	17.5	18.1	19.0	19.9
10	..	23.3	8.5	25.2	23.0	21.9	20.1	19.3	18.5	19.3	20.7	10.5	11.9	12.7	15.1	17.4	17.9	18.7	19.9
11	..	23.2	8.7	25.3	22.9	21.7	20.1	19.1	17.8	19.3	20.5	10.2	11.5	12.2	14.8	15.7	17.6	18.7	19.7
12	..	22.7	7.7	24.8	22.5	21.3	20.3	18.8	17.5	19.0	20.2	10.2	11.4	12.2	14.7	16.5	17.3	18.6	19.4
13	..	23.1	9.8	24.9	22.6	21.4	20.3	18.6	17.4	18.8	20.3	10.7	11.8	12.6	14.7	16.5	17.3	18.3	19.3
14	..	23.5	8.8	25.5	22.9	21.7	20.2	18.8	17.5	18.6	20.0	10.8	12.1	12.7	15.0	16.5	17.2	18.2	19.2
15	..	23.7	9.9	25.5	23.0	21.9	20.4	18.9	17.7	18.8	20.1	11.1	12.2	12.9	15.1	16.9	17.3	18.2	19.2
16	..	23.4	9.3	25.0	22.6	21.5	20.5	18.8	17.3	18.5	19.7	10.8	11.8	12.6	14.8	16.5	17.4	18.3	19.1
17	..	23.4	10.2	24.9	22.5	21.3	19.0	18.5	17.2	18.4	19.0	10.9	11.9	12.7	14.8	16.5	17.4	18.0	18.9
18	..	23.1	10.6	24.4	22.2	21.0	18.9	18.4	17.2	18.4	19.3	11.8	12.7	13.4	15.3	16.8	17.1	18.0	18.8
19	..	22.5	10.1	24.5	22.4	21.4	19.3	18.7	17.6	18.5	19.2	12.1	13.0	13.6	15.6	17.0	17.3	18.1	18.9
20	..	23.2	11.8	25.7	23.5	22.0	19.6	19.2	18.2	18.7	19.3	13.7	14.6	15.2	16.8	17.3	17.5	18.2	18.9
21	..	24.6	9.0	25.8	23.7	22.7	20.3	19.8	18.3	19.0	19.2	10.8	12.2	13.1	15.6	17.4	18.0	18.5	19.0
22	..	22.2	9.2	24.9	23.0	21.7	19.6	19.1	17.9	18.9	20.0	10.8	11.9	12.7	15.0	16.8	17.7	18.6	19.3
23	..	22.6	8.4	25.1	22.6	21.8	20.5	18.9	17.4	18.9	19.8	10.3	11.4	12.2	14.6	16.4	17.4	18.4	19.2
24	..	23.2	9.7	25.2	22.6	21.5	19.7	18.7	17.4	18.8	19.8	11.1	12.1	13.3	15.1	16.6	17.1	18.2	18.9
25	..	23.7	10.6	25.6	23.5	21.7	20.4	18.9	17.4	18.8	19.8	11.7	12.7	13.8	15.6	17.0	17.5	18.1	18.8
26	..	24.8	10.4	26.0	23.5	22.2	19.7	19.3	17.7	18.6	19.7	12.2	13.2	13.7	15.7	17.1	17.6	18.2	18.8
27	..	24.9	10.2	26.2	23.5	22.4	19.9	19.4	17.9	18.8	19.6	12.2	13.2	13.7	15.7	17.1	17.6	18.1	18.9
28	..	24.8	10.6	26.4	23.8	22.5	20.0	19.5	17.9	18.9	19.4	12.1	13.1	13.8	16.0	17.1	17.6	18.5	19.2
29	..	24.1	10.6	25.4	23.1	21.9	20.0	19.4	17.9	18.9	19.9	11.9	12.9	13.6	15.6	17.4	17.8	18.4	19.1
30	..	23.8	10.0	25.4	23.1	21.9	20.0	19.2	17.6	18.9	19.9	11.7	12.8	13.6	15.5	17.2	17.7	18.4	19.1
31	..	23.7	8.6	25.6	23.1	21.7	21.4	19.2	17.6	18.8	19.8	10.9	12.1	12.9	15.2	17.0	17.7	18.3	19.1
Mean	23.5	9.6	25.4	23.0	21.9	20.2	19.1	17.9	19.1	20.2	11.3	12.4	13.1	15.3	16.9	17.7	18.6	19.5

January 1913.

Date.		Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.															
			Max.	Min.	Maximum.					Minimum.										
					1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
			°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C
1	23.7	9.4	25.5	23.4	21.7	20.3	19.1	17.6	18.7	19.7	11.4	12.3	13.0	15.5	16.9	17.5	18.2	18.9
2	24.3	9.4	25.3	23.1	21.8	20.3	19.0	17.6	18.6	19.7	11.8	12.7	13.4	15.5	17.0	17.5	18.2	18.8
3	24.1	9.1	25.3	22.5	21.1	20.1	18.9	17.4	18.5	19.6	11.5	12.6	13.3	15.2	16.9	17.5	18.3	18.8
4	22.6	9.0	23.6	21.3	20.5	20.2	18.6	17.4	18.5	19.6	11.5	12.5	13.2	15.1	16.1	17.2	18.1	18.7
5	23.8	9.9	25.6	22.8	21.3	20.2	18.6	17.4	18.4	19.4	11.4	12.5	13.1	15.1	16.6	17.3	18.1	18.6
6	24.6	9.7	25.8	23.1	21.8	20.5	18.9	17.6	18.4	19.2	11.5	12.6	13.3	15.5	16.7	17.2	18.1	18.6
7	24.3	10.6	25.4	23.1	21.9	20.2	18.9	17.9	18.5	19.3	..	..	..	..	..	..	..	..
8	23.8	9.6	25.5	23.0	21.7	19.9	18.9	17.6	18.6	19.0	..	..	..	..	..	..	..	..
9	24.1	9.4	25.1	22.8	21.5	19.9	18.9	17.4	18.4	19.0	10.9	12.0	12.8	15.0	16.5	17.1	18.1	18.6
10	24.2	7.4	25.2	22.8	21.4	19.9	18.7	17.2	18.4	19.1	9.7	10.9	12.4	14.8	16.2	17.1	17.8	18.6
11	23.3	6.3	24.5	22.1	20.8	19.3	18.2	16.8	18.4	19.3	8.8	10.2	11.2	13.7	15.6	16.4	17.6	18.3
12	22.8	6.8	24.2	21.6	20.3	19.6	17.8	16.4	18.1	19.3	9.1	10.3	11.2	13.7	15.2	16.1	17.2	18.0
13	23.3	6.9	24.3	21.9	20.5	18.4	17.8	16.4	17.6	18.7	9.5	10.8	11.6	13.8	15.5	16.4	17.1	17.8
Mean	23.8	8.7	25.0	22.6	21.3	19.9	18.6	17.3	18.4	19.3	10.6	11.8	12.6	14.8	16.3	17.0	17.9	18.5

SOIL TEMPERATURES

February 1913

January 1913

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.															
		Max.	Min.	Maximum.						Minimum.									
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
1	..	24.4	7.5	24.1	24.0	24.0	23.9	23.4	24.4	23.3	26.8	10.3	11.4	12.3	14.2	15.9	16.2	16.8	17.1
2	..	25.3	8.0	24.9	22.5	22.5	19.4	18.8	16.9	17.6	18.3	10.3	11.5	12.3	14.5	16.4	16.6	17.2	17.7
3	..	25.7	8.3	27.1	24.9	22.8	19.7	18.9	17.3	17.9	18.9	10.8	11.9	12.8	14.8	16.5	17.1	17.4	17.8
4	..	26.0	8.1	27.3	24.6	22.9	19.9	19.2	17.4	18.1	19.2	10.6	11.7	12.7	15.1	16.4	17.0	17.3	17.8
5	..	26.2	8.7	27.3	25.2	23.5	20.2	19.4	18.0	18.5	..	10.9	11.9	13.0	15.1	16.6	17.2	17.4	18.2
6	..	27.0	9.4	27.7	25.0	23.6	20.5	19.7	18.2	18.7	..	11.9	13.0	13.9	15.7	16.9	17.2	17.8	18.2
7	..	27.2	10.9	27.8	25.3	24.6	21.3	20.3	19.1	19.3	18.9	12.8	13.6	14.6	16.3	17.2	17.8	18.1	18.7
8	..	27.6	13.2	28.8	26.6	24.6	21.3	20.3	19.1	19.3	19.6	12.8	13.6	14.6	16.3	17.2	17.8	18.1	18.7
9	..	22.0	10.1	22.5	21.1	20.8	20.0	20.1	18.5	19.3	19.2	12.9	13.9	14.8	16.7	17.7	18.3	18.8	19.2
10	..	26.6	13.0	30.9	28.2	25.7	22.0	21.0	19.3	19.6	19.4	15.5	16.1	16.7	18.1	18.6	18.5	19.1	19.3
11	0.03	21.8	15.1	22.0	20.8	20.4	19.6	19.3	18.8	19.6	19.5	15.7	16.1	16.8	18.1	18.2	18.7	19.1	19.5
12	..	27.3	13.9	31.5	29.0	26.5	23.0	21.7	20.2	20.0	19.6	16.3	16.9	17.6	18.3	18.5	18.7	19.1	19.3
13	..	25.4	10.1	31.0	28.2	26.2	22.7	21.8	20.1	20.5	20.0	13.6	14.6	15.7	16.8	18.0	18.7	19.1	19.5
14	..	25.4	12.1	30.3	27.9	25.7	23.0	21.8	20.1	20.7	20.4	13.6	14.6	15.7	16.8	18.0	18.7	19.1	19.3
15	0.07	18.8	14.4	20.1	19.5	19.8	20.4	20.1	20.0	20.6	20.5	16.5	17.0	17.4	18.4	18.9	19.5	20.1	20.6
16	0.51	19.1	13.8	21.8	20.3	19.9	19.5	19.5	19.0	20.4	20.5	15.1	15.9	16.5	17.6	18.3	19.1	20.3	20.6
17	..	23.2	10.2	26.5	24.1	23.4	21.2	20.5	19.0	20.0	20.1	11.6	12.8	14.0	16.3	17.7	18.5	19.3	20.5
18	..	23.3	9.9	27.2	25.0	23.8	21.5	20.3	19.0	19.9	20.0	12.0	13.3	14.4	16.7	17.7	18.9	19.3	20.1
19	..	25.0	10.2	28.8	26.2	24.8	22.1	20.8	19.5	20.0	20.0	12.6	13.8	14.8	17.1	17.8	18.8	19.3	20.0
20	..	26.4	11.6	30.3	27.6	25.7	22.8	21.3	20.0	20.1	20.0	13.4	14.6	15.6	17.2	18.2	19.0	19.4	20.1
21	..	28.1	13.7	31.0	28.5	26.4	23.3	21.9	20.3	20.5	20.2	14.6	15.6	16.5	18.7	19.4	19.6	19.8	20.2
22	..	27.7	13.3	31.5	28.5	26.4	23.6	22.3	20.6	20.7	20.5	14.9	16.0	16.7	18.7	19.7	20.2	20.5	21.0
23	..	27.7	13.3	32.7	30.4	28.1	24.9	23.3	21.6	21.4	21.0	15.5	16.6	17.6	19.7	19.7	20.2	20.5	21.0
24	0.44	31.0	16.8	33.7	31.2	28.9	25.5	23.8	22.4	21.9	21.4	18.3	18.9	19.8	20.7	21.2	21.4	21.3	21.5
25	..	29.0	15.1	32.7	30.4	28.1	24.9	23.3	21.6	21.4	21.0	15.5	16.6	17.6	18.9	19.7	20.4	21.1	21.6
26	0.38	21.6	13.5	23.1	22.2	21.9	21.6	21.4	21.4	21.5	21.4	13.7	15.4	16.5	18.9	20.1	20.6	21.0	21.4
27	..	26.7	11.9	30.2	27.7	26.3	24.2	22.6	21.5	21.5	21.4	13.7	15.4	16.5	18.9	20.1	20.6	21.0	21.4
28	..	23.8	10.4	28.4	25.7	24.3	22.5	21.8	21.4	21.4	21.3	11.7	13.2	14.2	17.1	18.9	19.9	20.4	21.3
Mean	..	25.3	11.6	27.9	24.1	21.8	20.9	19.8	20.1	20.4	20.4	13.8	14.7	15.6	17.3	18.3	18.8	19.2	19.7

March 1913.

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.							
		Max.	Min.	Maximum.				Minimum.			
				1"	2"	3"	6"	9"	12"	18"	24"
1	..	25.7	9.9	°C 27.5	°C 25.0	°C 23.9	°C 21.9	°C 21.1	°C 19.7	°C 21.2	°C 21.3
2	..	26.7	9.1	°C 28.0	°C 25.4	°C 24.1	°C 21.9	°C 20.9	°C 19.6	°C 20.7	°C 20.9
3	..	26.2	12.3	°C 27.4	°C 24.8	°C 23.5	°C 21.5	°C 20.7	°C 19.7	°C 20.5	°C 20.6
4	..	28.9	14.0	°C 30.4	°C 27.6	°C 26.1	°C 23.2	°C 21.7	°C 20.4	°C 20.7	°C 20.6
5	0.35	26.7	15.8	°C 26.2	°C 24.2	°C 23.4	°C 22.5	°C 21.4	°C 20.7	°C 21.0	°C 21.0
6	0.01	21.2	11.6	°C 23.5	°C 21.9	°C 21.5	°C 21.8	°C 20.7	°C 20.5	°C 21.0	°C 21.0
7	..	24.0	11.6	°C 20.2	°C 26.0	°C 24.7	°C 22.5	°C 21.3	°C 20.2	°C 20.8	°C 20.9
8	..	25.0	12.2	°C 28.1	°C 25.5	°C 24.4	°C 22.8	°C 21.3	°C 20.0	°C 21.1	°C 21.1
9	..	27.6	14.1	°C 31.6	°C 28.5	°C 26.3	°C 24.5	°C 22.2	°C 20.9	°C 21.5	°C 21.5
10	..	27.6	14.8	°C 32.4	°C 29.2	°C 27.3	°C 24.7	°C 22.9	°C 21.2	°C 22.0	°C 22.0
11	0.07	29.8	16.7	°C 33.9	°C 30.9	°C 29.0	°C 25.9	°C 23.9	°C 22.4	°C 22.5	°C 22.5
12	..	29.9	14.0	°C 33.3	°C 30.4	°C 28.9	°C 26.3	°C 24.4	°C 22.8	°C 22.5	°C 22.5
13	..	28.2	11.4	°C 33.6	°C 30.1	°C 28.2	°C 25.9	°C 23.9	°C 22.9	°C 22.5	°C 22.5
14	..	29.0	11.8	°C 33.3	°C 29.9	°C 28.1	°C 25.4	°C 23.7	°C 22.6	°C 22.5	°C 22.5
15	..	29.8	11.6	°C 33.7	°C 30.3	°C 28.5	°C 25.5	°C 23.8	°C 22.7	°C 22.5	°C 22.5
16	..	31.4	13.5	°C 35.6	°C 32.0	°C 30.6	°C 28.8	°C 26.1	°C 24.8	°C 22.7	°C 22.7
17	..	31.4	13.3	°C 35.7	°C 32.0	°C 30.3	°C 28.5	°C 26.4	°C 24.8	°C 22.9	°C 22.9
18	..	31.9	18.7	°C 35.1	°C 31.8	°C 30.1	°C 28.4	°C 26.4	°C 24.9	°C 23.7	°C 23.7
19	..	33.3	17.7	°C 37.0	°C 34.4	°C 32.0	°C 28.0	°C 26.3	°C 24.1	°C 23.9	°C 23.9
20	..	32.3	13.0	°C 36.2	°C 32.9	°C 31.2	°C 28.4	°C 26.3	°C 24.2	°C 24.1	°C 24.1
21	..	29.5	10.3	°C 34.5	°C 31.1	°C 29.2	°C 27.0	°C 25.3	°C 24.2	°C 24.1	°C 24.1
22	..	30.9	13.8	°C 34.9	°C 31.1	°C 29.2	°C 26.9	°C 24.7	°C 23.8	°C 23.8	°C 23.8
23	..	31.4	13.0	°C 33.8	°C 30.6	°C 28.9	°C 26.5	°C 24.6	°C 23.7	°C 23.5	°C 23.5
24	..	32.1	14.2	°C 35.7	°C 31.9	°C 30.0	°C 26.6	°C 25.0	°C 23.8	°C 23.4	°C 23.4
25	..	33.7	13.7	°C 36.9	°C 33.5	°C 31.5	°C 27.2	°C 25.8	°C 24.6	°C 24.2	°C 24.2
26	..	35.4	16.7	°C 37.9	°C 34.1	°C 32.3	°C 28.5	°C 26.5	°C 24.6	°C 24.2	°C 24.2
27	..	37.2	18.3	°C 39.0	°C 35.4	°C 33.5	°C 29.2	°C 27.4	°C 25.4	°C 24.8	°C 24.8
28	..	38.2	17.7	°C 39.5	°C 36.2	°C 34.1	°C 30.3	°C 28.3	°C 26.0	°C 25.8	°C 25.8
29	..	37.0	17.3	°C 38.5	°C 35.1	°C 33.5	°C 31.2	°C 28.3	°C 26.0	°C 25.5	°C 25.5
30	..	33.7	15.7	°C 37.6	°C 34.7	°C 32.8	°C 29.8	°C 27.9	°C 26.0	°C 25.9	°C 25.9
31	..	33.7	15.7	°C 37.6	°C 34.7	°C 32.8	°C 29.8	°C 27.9	°C 26.0	°C 25.9	°C 25.9
Mean	30.2	13.9	°C 33.4	°C 30.2	°C 28.6	°C 25.8	°C 24.1	°C 22.7	°C 22.8	°C 22.5

SOIL TEMPERATURES

April 1913.

Date.	Rain inches.	SOIL TEMPERATURE.																
		Maximum.							Minimum.									
		AIR (SHADE).		1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
Max.	Min.	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C
1	..	35.3	17.6	37.7	34.9	33.2	29.3	27.9	25.6	25.1	18.3	19.8	21.0	23.3	24.4	25.1	25.2	25.3
2	..	35.2	18.7	38.5	35.5	33.7	29.6	28.3	26.0	25.5	19.6	20.7	21.8	23.4	24.5	25.2	25.6	25.3
3	..	35.3	20.1	38.8	36.0	34.3	30.0	28.8	26.5	26.4	20.9	22.0	22.8	24.1	24.9	25.6	25.7	25.3
4	..	35.4	19.5	39.5	36.2	35.0	31.2	29.4	27.0	26.6	21.5	22.6	23.5	25.0	25.7	26.1	26.1	26.0
5	..	32.1	18.9	37.8	35.4	33.8	30.3	29.2	27.0	26.9	21.0	22.2	23.2	25.2	26.2	26.5	26.7	26.3
6	..	33.3	20.6	39.7	36.8	35.1	31.3	29.8	27.4	27.1	22.4	23.5	24.1	25.2	26.2	26.6	26.7	26.3
7	..	36.4	16.6	40.5	37.5	35.9	31.9	30.4	28.5	27.6	20.9	22.4	23.4	25.9	26.7	27.2	27.1	26.7
8	..	37.1	20.4	40.0	36.7	35.1	32.1	30.2	28.5	27.7	22.3	23.3	24.1	26.1	27.1	27.6	27.5	27.0
9	..	36.6	23.0	39.9	36.9	35.4	32.0	30.6	28.7	27.3	24.3	25.1	25.6	26.5	27.1	27.7	27.8	27.3
10	..	36.5	21.1	40.7	37.7	36.0	33.0	31.2	29.2	28.5	23.8	24.7	25.5	27.4	27.7	28.4	28.2	27.5
11	..	38.4	21.5	41.3	38.3	36.8	34.1	31.8	29.5	29.0	24.3	25.3	26.3	27.7	28.1	29.1	28.5	28.1
12	..	38.3	19.7	41.5	39.5	37.1	33.9	32.1	30.0	29.4	24.3	24.4	25.3	27.7	28.0	29.2	28.9	28.3
13	..	39.9	19.6	39.9	37.3	35.8	33.4	31.7	29.8	29.5	21.5	23.0	24.3	26.7	28.2	29.2	28.8	28.5
14	..	40.0	21.1	40.3	37.4	35.8	33.4	31.5	29.7	29.4	21.6	23.0	24.5	26.8	28.1	28.8	28.9	28.8
15	..	40.7	24.0	40.1	36.5	35.0	32.9	31.2	29.5	29.3	23.9	24.8	25.6	27.5	28.2	28.9	28.9	28.6
16	..	40.7	20.7	38.7	35.8	34.3	32.5	30.8	29.2	28.7	20.9	22.3	23.6	26.3	27.6	28.6	28.9	28.8
17	..	40.9	20.4	39.3	35.2	34.7	32.5	30.8	29.0	29.1	21.1	22.5	23.7	26.4	27.6	28.2	29.0	28.8
18	..	41.3	21.1	40.4	37.4	35.7	33.7	31.3	29.5	29.3	22.6	23.9	24.7	26.7	28.0	28.5	28.8	28.8
19	..	41.3	22.3	41.2	38.3	36.7	33.8	31.8	29.7	29.0	24.2	25.3	26.2	27.3	28.0	28.8	29.0	29.0
20	..	40.3	23.1	40.9	37.9	36.4	33.8	32.0	30.0	29.7	23.1	24.3	25.1	27.5	28.3	29.3	29.5	29.1
21	..	41.3	23.9	39.0	36.6	35.2	33.4	31.9	30.2	29.0	22.2	23.5	24.7	27.2	28.6	29.5	29.4	29.3
22	..	42.0	23.7	42.5	39.6	37.8	34.2	32.7	30.5	30.2	25.2	26.2	27.1	27.6	28.8	29.6	29.7	29.3
23	..	38.9	22.3	42.1	39.1	37.4	34.3	32.8	30.9	29.7	24.6	25.8	26.6	28.7	29.7	30.3	30.2	29.8
24	..	43.1	24.6	43.5	41.3	38.8	35.2	33.6	31.5	30.8	24.4	25.8	26.7	28.9	29.7	30.5	30.2	30.0
25	..	42.1	24.2	42.5	39.5	38.1	35.2	33.6	31.7	31.0	24.2	25.4	26.6	28.9	30.2	30.6	30.5	30.3
26	..	43.1	22.0	42.0	38.9	37.5	34.7	33.4	31.4	31.1	23.9	25.4	26.2	28.6	30.2	30.7	30.8	30.6
27	..	42.4	23.9	41.8	39.1	37.7	34.7	33.4	31.9	31.4	24.9	26.3	27.2	29.4	31.0	31.2	31.0	30.8
28	..	43.1	22.8	43.9	41.7	39.5	35.9	34.4	32.4	31.6	25.9	27.0	28.0	30.2	31.1	31.7	30.9	30.8
29	..	43.8	24.2	44.2	41.0	39.5	36.0	34.8	32.5	32.0	25.7	27.2	28.1	30.6	31.3	31.7	31.4	31.4
30	..	43.6	22.2	43.4	40.6	39.1	36.7	34.8	32.4	32.1	25.1	26.7	27.5	30.2	31.2	31.9	32.0	31.7
Mean..	..	39.3	21.4	40.7	37.8	36.2	33.2	31.5	29.5	29.1	22.9	24.1	25.1	27.1	28.1	28.7	28.7	28.5

May 1913.

Date.		Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.													
			Max.	Min.	Minimum.													
					1"	2"	3"	6"	9"	12"	18"	24"						
			°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	
1	..	..	43.7	23.2	43.6	39.4	36.6	34.8	32.9	32.3	31.6	29.7	27.6	26.3	25.0	23.4	21.4	19.4
2	..	..	43.3	26.4	41.3	37.8	35.8	34.2	32.5	32.3	31.6	30.8	28.6	27.8	26.6	25.4	24.2	22.4
3	..	..	43.1	22.3	42.4	39.8	35.9	34.7	32.7	32.4	31.8	29.7	27.6	25.6	24.2	22.8	21.6	19.6
4	..	..	43.0	21.4	43.4	39.1	36.1	34.7	32.7	32.6	32.0	29.7	27.6	25.9	24.6	23.3	22.1	20.1
5	..	..	41.7	22.8	43.1	40.2	38.6	34.5	32.6	32.4	31.9	29.7	27.6	25.9	24.6	23.3	22.1	20.1
6	..	..	34.9	21.3	40.3	38.0	34.8	33.7	32.0	32.1	31.5	29.5	27.3	26.3	25.2	23.9	22.7	20.7
7	..	..	36.4	22.8	41.9	38.4	34.5	33.4	31.5	32.1	31.5	29.5	27.3	26.3	25.2	23.9	22.7	20.7
8	0.44	..	37.6	21.3	42.4	39.6	35.4	33.9	32.0	31.7	31.2	29.4	27.3	26.3	25.2	23.9	22.7	20.7
9	1.18	..	28.8	19.3	32.1	30.3	29.6	30.5	29.4	30.7	31.1	29.4	27.3	26.3	25.2	23.9	22.7	20.7
10	..	..	34.3	23.2	37.6	34.6	33.3	31.8	29.1	30.1	30.4	27.6	25.2	24.6	23.4	22.2	21.0	19.0
11	..	..	36.4	24.5	39.7	37.3	33.1	31.3	30.4	30.0	29.7	27.6	25.2	24.6	23.4	22.2	21.0	19.0
12	0.03	..	36.3	21.2	40.9	38.2	33.0	31.7	30.0	30.0	29.9	27.6	25.2	24.6	23.4	22.2	21.0	19.0
13	..	..	34.0	22.8	40.0	37.2	34.2	31.5	30.3	30.0	29.9	27.6	25.2	24.6	23.4	22.2	21.0	19.0
14	..	..	35.1	22.2	42.1	39.5	34.9	32.7	30.9	30.5	30.2	28.7	26.4	25.6	24.4	23.2	22.0	20.0
15	0.18	..	32.8	20.7	38.6	36.2	33.4	31.2	29.3	30.5	30.2	28.7	26.4	25.6	24.4	23.2	22.0	20.0
16	..	..	32.3	22.6	40.9	38.5	33.6	32.1	30.3	30.3	30.0	28.7	26.4	25.6	24.4	23.2	22.0	20.0
17	..	..	35.2	20.6	40.6	37.8	36.1	32.2	31.3	30.2	30.0	28.7	26.4	25.6	24.4	23.2	22.0	20.0
18	1.15	..	33.0	21.2	38.3	35.5	32.3	31.3	29.4	30.2	30.0	28.7	26.4	25.6	24.4	23.2	22.0	20.0
19	..	..	31.8	22.3	36.1	33.9	32.9	30.8	29.5	30.0	30.0	28.7	26.4	25.6	24.4	23.2	22.0	20.0
20	..	..	34.0	24.1	38.8	36.5	33.2	31.2	29.7	29.8	29.9	27.7	26.7	25.7	24.4	23.2	22.0	20.0
21	..	..	35.3	22.7	40.8	38.0	33.4	31.8	30.3	30.2	30.0	28.7	26.4	25.6	24.4	23.2	22.0	20.0
22	0.26	..	35.6	23.4	42.3	39.4	34.4	32.6	31.0	30.8	30.5	29.5	28.0	26.7	25.4	24.2	23.0	21.0
23	..	..	35.7	23.7	39.7	37.6	34.5	32.6	30.9	30.8	30.3	29.1	27.0	26.3	25.1	23.9	22.7	20.7
24	..	..	37.8	25.1	42.4	39.5	35.4	33.3	31.9	31.3	30.9	29.6	28.1	27.3	26.1	24.9	23.7	21.7
25	..	..	39.7	25.8	43.0	40.5	35.5	34.2	32.8	31.9	31.2	29.8	28.1	27.3	26.1	24.9	23.7	21.7
26	..	..	38.4	23.8	44.1	41.8	37.0	35.2	33.2	32.5	31.8	29.8	28.1	27.3	26.1	24.9	23.7	21.7
27	0.53	..	32.8	20.3	36.4	34.5	33.2	32.4	31.5	32.4	31.7	29.6	28.6	27.9	26.8	25.7	24.5	22.5
28	..	..	35.9	25.3	39.4	37.4	34.0	32.5	31.7	31.7	31.5	29.6	28.6	27.9	26.8	25.7	24.5	22.5
29	..	..	32.0	20.4	37.7	34.9	32.7	31.4	30.7	31.4	31.0	29.3	28.4	27.7	26.6	25.5	24.3	22.3
30	0.13	..	27.2	20.3	29.1	29.4	30.0	29.7	29.2	31.0	31.0	28.4	28.4	27.1	26.0	24.9	23.7	21.7
31	1.42	..	31.8	18.5	35.4	32.9	31.1	29.8	29.1	29.9	30.3	28.1	26.6	25.5	24.3	23.2	22.0	20.0
Mean..	..	..	35.8	22.4	39.8	37.4	33.8	32.4	30.9	31.1	30.8	28.3	26.3	25.5	24.4	23.2	22.0	20.0

July 1913.

Date.	Rain. inches.	AIR (SHADE).		SOIL TEMPERATURE.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
		Max.	Min.	Maximum.						Minimum.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
1	2.0	28.3	24.4	31.5	30.0	29.6	29.0	28.9	29.0	29.7	29.7	25.9	26.6	27.0	27.6	28.1	28.5	29.1	29.7	29.7	28.5	29.1	29.7	29.5	29.5	29.5	29.5	30.1	30.4	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.6	30.

SOIL TEMPERATURES

October 1913.

Date.		Rain inches.	SOIL TEMPERATURE.																		
			AIR (SHADE).		Maximum.								Minimum.								
			Max.	Min.	1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"	
25	31.3	18.3	34.5	30.8	31.1	28.4	27.8	27.3	27.7	28.0	20.6	21.9	25.4	24.6	25.5	26.2	26.8	27.6	
26	30.4	18.4	34.2	31.6	30.7	28.3	27.7	27.1	27.2	27.4	20.7	21.9	23.1	25.0	25.2	26.2	26.8	27.5	
27	30.7	18.7	35.2	32.1	31.0	28.4	27.8	27.0	27.1	27.3	20.7	22.1	23.1	25.1	25.4	26.3	26.8	27.3	
28	30.4	18.1	35.9	32.3	31.4	28.6	27.8	27.2	27.1	27.3	20.6	22.0	22.9	24.9	26.1	26.2	26.8	27.3	
29	29.9	16.9	35.6	31.3	30.4	28.0	27.5	26.9	27.1	27.2	20.1	21.6	22.5	24.4	25.1	25.9	26.6	27.2	
30	29.3	16.7	34.3	31.3	30.5	27.9	27.2	26.8	26.9	27.1	19.6	21.2	22.2	24.2	24.8	25.6	26.5	..	
31	29.3	16.2	35.1	31.4	30.5	27.9	27.1	26.7	26.8	27.0	19.4	20.8	22.0	23.9	25.0	25.6	26.2	26.9	
Mean...		..	30.2	17.6	35.0	31.5	30.8	28.2	27.6	27.0	27.1	27.3	20.2	21.6	23.0	24.6	25.3	26.0	26.6	27.3	

November 1913.

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.															
		Max.	Min.	Maximum.						Minimum.									
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
1	..	29.4	16.7	33.7	30.3	23.7	27.4	26.8	26.0	26.5	26.7	19.6	20.9	22.1	23.8	24.7	25.6	26.3	26.8
2	..	28.8	16.2	33.7	30.7	29.6	27.4	26.7	26.0	26.5	26.6	18.9	20.6	21.6	23.7	24.4	25.3	25.9	26.6
3	..	28.8	15.4	33.2	30.3	29.3	27.0	26.5	26.0	26.3	26.5	19.1	20.2	21.2	23.5	24.4	25.2	25.6	26.4
4	..	29.1	15.6	33.2	30.3	29.2	26.8	26.2	25.8	26.3	26.4	19.5	20.0	20.9	23.4	24.4	24.9	25.4	26.2
5	..	29.3	16.4	34.1	30.4	29.2	26.9	26.2	25.2	25.9	26.0	19.0	20.4	21.4	23.2	23.9	24.7	25.3	26.1
6	..	29.5	15.4	33.8	30.5	29.2	26.9	26.2	25.0	25.7	26.0	18.3	19.8	20.8	22.8	24.0	24.7	25.3	26.1
7	..	29.7	15.1	32.7	29.8	28.6	26.4	25.8	25.5	25.7	25.8	18.1	19.6	20.6	22.9	24.1	24.5	25.2	25.9
8	..	29.2	12.8	33.1	29.7	28.5	26.2	25.5	24.8	25.5	25.7	16.7	18.2	19.3	21.5	22.6	23.1	24.1	25.0
9	..	27.8	12.2	30.8	28.2	27.3	25.4	24.8	24.6	25.3	25.5	16.1	17.5	18.7	21.5	22.6	23.5	24.8	25.7
10	..	26.7	13.4	31.0	28.0	27.0	26.0	24.3	24.3	24.8	25.3	16.4	17.5	19.0	21.3	22.4	23.3	24.0	24.9
11	..	28.7	14.5	31.3	28.6	27.6	25.0	24.3	24.1	24.5	24.9	16.5	17.9	19.3	21.6	22.4	23.3	24.0	24.9
12	..	28.7	12.7	32.2	28.6	27.4	25.2	24.3	23.7	24.3	24.7	16.5	17.9	19.2	21.6	22.2	23.2	24.0	24.8
13	..	28.4	14.0	31.7	28.4	27.2	25.2	24.2	23.6	24.2	24.5	16.9	18.4	19.3	21.2	22.2	23.0	23.9	24.6
14	..	28.2	14.1	31.2	28.0	27.0	25.0	24.1	23.6	24.2	24.5	17.0	18.2	19.2	21.2	22.2	22.9	23.8	24.5
15	..	28.8	12.6	31.3	27.9	27.0	24.9	23.9	23.6	24.2	24.5	15.6	17.2	18.3	21.4	22.1	22.9	23.7	24.4
16	..	29.1	12.8	31.0	27.4	26.4	24.6	23.7	23.4	23.9	24.2	15.8	17.0	18.3	20.8	21.6	22.5	23.2	23.8
17	..	29.5	12.2	31.3	28.0	26.8	24.8	23.7	23.5	23.6	24.2	15.6	17.0	18.2	20.7	21.5	22.3	22.9	23.8
18	..	28.2	12.7	30.5	27.8	26.5	24.1	23.4	22.9	23.4	23.7	14.6	16.4	17.6	20.1	21.2	22.2	22.8	23.9
19	..	27.1	14.1	29.5	27.0	25.8	23.7	23.2	22.4	23.3	23.6	15.8	17.0	18.1	20.3	21.2	22.1	22.8	23.8
20	..	27.2	13.0	30.1	27.6	26.2	23.8	23.2	22.4	23.1	23.5	15.6	16.8	18.0	20.3	21.2	22.1	22.8	23.7
21	..	27.1	11.8	29.1	26.9	25.8	23.6	23.2	22.1	23.0	23.5	14.7	16.0	17.4	19.8	20.8	21.9	22.8	23.6
22	..	27.0	12.7	29.5	26.8	25.6	23.4	22.8	21.8	22.9	23.4	15.1	16.5	17.6	19.8	20.9	21.9	22.7	23.6
23	..	26.8	13.6	27.1	25.4	24.4	23.1	22.4	21.8	22.7	23.3	15.4	16.7	17.9	20.2	21.1	21.6	22.6	23.4
24	..	26.4	11.7	28.0	25.8	24.7	22.7	22.3	21.7	22.5	23.0	13.9	15.5	16.7	19.1	20.2	21.2	22.2	23.3
25	..	26.0	11.1	28.8	26.1	24.8	22.7	22.2	21.2	22.4	22.8	13.6	15.1	16.3	19.1	20.0	21.0	22.0	22.9
26	..	25.9	10.1	28.2	25.8	24.5	22.7	22.2	21.2	22.2	22.6	12.7	14.5	15.7	18.6	19.7	20.7	21.5	22.7
27	..	25.6	9.4	27.9	25.4	24.1	23.1	21.6	20.8	22.3	22.6	12.0	13.8	15.1	18.0	19.2	20.3	21.4	22.6
28	..	25.4	9.0	27.8	25.0	23.7	21.7	21.2	20.1	21.9	22.5	11.9	13.6	14.9	17.8	18.8	20.0	21.2	22.2
29	..	25.4	10.9	27.4	24.8	23.4	21.4	20.9	20.0	21.4	20.0	13.3	14.7	15.7	18.0	18.9	19.9	20.8	21.9
30	..	25.9	12.7	27.9	25.4	24.1	21.6	21.2	..	21.2	21.8	14.9	16.0	16.9	18.9	19.4	19.9	20.8	21.9
Mean	27.8	13.2	30.7	27.9	26.7	24.6	23.9	23.4	24.0	24.3	16.0	17.4	18.5	20.9	21.8	22.7	23.5	24.3

December 1913.

Date.	Rain inches.	AIR (SHADE).		Maximum.								Minimum.																							
		Max.	Min.	1°				2°				3°				6°				9°				12°				18°				24°			
				°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F		
1	..	26.5	13.3	28.1	25.8	24.5	22.2	21.6	21.3	21.4	21.7	14.7	16.0	16.9	19.1	19.7	20.3	21.0	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9			
2	..	27.2	11.6	29.3	26.5	25.0	23.0	21.8	21.6	21.5	21.8	13.9	15.4	16.5	18.8	19.7	20.5	21.1	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0			
3	..	26.1	11.7	29.6	25.8	24.6	22.5	21.8	21.6	21.5	21.8	13.9	15.4	16.7	18.8	19.6	20.5	21.3	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0			
4	..	26.6	11.6	28.4	25.6	24.4	22.4	21.6	21.4	21.5	21.8	13.9	15.3	16.4	18.8	19.4	20.4	21.2	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0			
5	..	26.5	14.9	27.8	25.5	24.3	22.0	21.4	21.3	21.5	21.7	16.8	17.5	18.2	19.6	19.9	20.4	21.1	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9			
6	0.15	21.8	15.8	22.0	21.3	21.0	20.5	20.4	20.9	21.4	21.7	17.4	18.0	18.5	19.7	19.9	20.4	20.7	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5			
7	..	22.3	13.5	25.9	23.6	22.7	21.3	21.0	21.0	21.3	21.6	14.2	15.4	16.5	18.4	19.2	20.1	20.8	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7			
8	..	24.8	13.3	27.3	24.9	23.8	21.6	21.1	20.9	21.2	21.6	14.0	15.3	16.3	18.5	19.2	20.1	20.8	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7			
9	..	21.9	13.6	25.1	23.0	22.3	20.9	20.7	20.5	21.1	21.5	13.8	15.2	16.2	18.2	18.9	19.8	20.7	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6			
10	..	25.8	10.6	26.8	24.5	23.5	21.1	20.8	20.8	21.0	21.5	12.7	14.4	15.5	18.2	18.7	19.7	20.7	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5			
11	..	23.7	10.0	26.6	24.0	22.9	20.8	20.4	20.3	20.9	21.3	12.5	14.0	15.2	17.4	18.4	19.5	20.4	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3			
12	0.09	24.3	12.3	27.1	24.0	22.9	20.6	20.4	20.2	20.8	21.2	14.1	15.5	16.5	18.1	18.6	19.3	20.2	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1			
13	0.87	17.2	13.6	18.9	18.7	18.3	18.5	18.9	19.6	20.5	21.0	14.0	15.8	16.3	17.5	18.0	18.7	19.8	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0			
14	0.02	21.3	11.4	24.5	22.6	21.6	19.8	19.3	19.4	20.0	20.7	13.9	15.0	15.7	17.2	17.8	18.5	19.0	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8	19.8			
15	..	20.4	10.2	26.5	23.9	22.2	20.0	19.6	19.3	19.8	20.5	12.5	13.6	14.4	16.5	17.3	18.3	18.9	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1			
16	..	22.6	11.1	25.9	23.5	22.2	20.0	19.5	19.2	19.7	20.3	11.5	12.9	13.8	16.2	17.2	18.2	18.5	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2			
17	..	22.7	9.3	26.4	23.3	22.1	19.7	19.2	19.0	19.6	20.2	10.2	11.8	12.8	15.5	16.7	17.9	19.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1			
18	..	22.5	9.3	25.4	22.6	21.5	19.3	18.8	18.7	19.4	20.0	9.9	11.6	12.6	15.2	16.4	17.6	18.7	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9			
19	..	23.1	7.8	25.2	22.4	21.1	18.9	18.5	18.4	19.1	19.8	8.8	10.6	11.7	14.4	15.8	17.2	18.6	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7	19.7			
20	..	22.5	6.2	24.6	21.7	20.5	18.4	17.9	18.1	18.8	19.6	8.0	10.0	11.1	13.9	15.4	16.7	18.1	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3			
21	..	21.9	8.4	23.9	20.9	19.8	17.8	17.5	17.5	18.5	19.3	8.7	10.4	11.4	13.8	15.2	16.4	17.7	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1			
22	..	23.1	9.2	23.8	21.1	19.8	17.6	17.3	17.3	18.1	18.8	9.7	11.0	11.9	14.9	15.3	16.4	17.7	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1			
23	..	24.4	9.4	24.4	21.9	20.7	18.4	17.6	17.5	18.2	18.8	10.9	12.1	12.8	14.8	15.5	16.5	17.6	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7			
24	..	24.0	8.8	25.7	22.0	20.8	19.6	18.0	17.5	18.1	18.8	8.4	10.4	11.5	13.8	15.3	16.8	17.8	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7			
25	..	20.9	6.7	24.9	21.1	20.1	19.3	17.5	17.7	18.1	18.8	7.8	9.6	10.5	13.2	14.6	16.2	17.4	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5			
26	..	20.8	5.8	23.7	20.2	19.1	18.2	16.6	16.6	17.6	18.4	7.8	9.6	10.5	13.2	14.6	16.2	17.4	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5			
27	..	20.7	5.5	23.8	20.1	19.1	18.2	16.6	16.6	17.6	18.4	7.8	9.6	10.5	13.2	14.6	16.2	17.4	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5			
28	..	21.1	6.6	24.0	20.1	19.5	17.7	16.5	16.4	17.2	18.1	7.4	9.7	10.8	13.2	14.2	15.5	16.8	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2			
29	..	21.1	5.6	24.1	20.1	19.5	17.9	16.3	16.3	17.0	17.9	7.7	9.7	10.6	13.5	14.1	15.3	16.5	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8			
30	..	21.5	5.1	24.0	19.9	19.4	18.2	16.1	16.0	16.9	17.7	7.4	9.1	10.2	12.5	13.6	14.6	16.3	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4			
31	..	23.0	7.2	24.9	20.4	19.6	17.9	16.3	16.0	16.8	17.5	8.8	10.5	11.3	13.2	14.3	15.2	16.2	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3			
Mean	..	23.0	10.0	25.4	22.6	21.6	19.8	19.1	19.0	19.6	20.1	11.5	13.0	13.9	16.1	17.0	18.1	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0			

January 1914.

Date.	Rain inches.	AIR (SHADE).		Maximum.								Minimum.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
		Max.	Min.	24"				18"				12"				9"				6"				3"				2"				1"																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
1	..	22.9	8.4	24.2	20.4	19.7	19.3	16.6	17.0	16.9	17.5	9.5	11.1	11.8	13.6	14.7	15.5	16.3	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	1

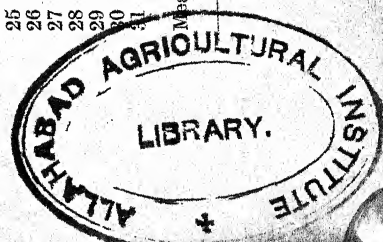
SOIL TEMPERATURES

February 1914.

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.															
		Max.	Min.	Maximum.						Minimum.									
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
1	..	25.4	9.7	24.6	21.9	20.9	18.6	18.1	17.6	18.0	18.3	10.8	12.5	12.6	15.2	15.9	16.9	17.5	18.1
2	..	25.9	9.8	24.7	21.9	20.8	18.5	18.1	17.7	18.0	18.3	11.0	12.6	13.4	15.3	15.9	16.9	17.6	18.2
3	..	25.8	10.0	24.5	21.9	20.8	18.4	18.1	17.8	18.1	18.3	11.2	12.9	13.6	15.5	16.1	17.0	17.6	18.2
4	..	26.7	10.5	24.8	22.1	21.1	18.7	18.3	18.0	18.2	18.4	11.6	13.2	14.1	15.8	16.3	17.1	17.7	18.3
5	..	26.8	11.6	24.7	22.2	21.1	18.8	18.4	18.1	18.4	18.5	12.1	13.7	14.5	16.2	16.6	17.3	17.9	18.4
6	..	24.8	9.0	24.6	22.2	21.2	18.9	18.5	18.3	18.4	18.6	10.7	12.6	13.5	15.7	16.3	17.4	18.0	18.6
7	..	24.4	8.9	24.1	21.6	20.5	18.4	18.1	18.0	18.4	18.6	9.9	11.7	12.8	14.8	15.7	16.9	17.8	18.5
8	..	26.6	10.0	24.2	21.4	20.4	18.1	17.8	17.6	18.2	18.6	10.5	12.3	13.1	15.0	15.9	16.8	17.6	18.4
9	..	28.0	11.8	24.7	22.0	20.9	18.3	18.0	17.6	18.0	18.4	12.5	14.0	14.7	16.4	16.5	16.9	17.6	18.2
10	..	28.6	12.8	25.0	22.6	21.5	18.9	18.5	18.1	18.3	18.5	12.3	13.8	14.7	16.3	16.2	17.2	17.7	18.3
11	..	28.2	9.8	25.6	22.9	21.7	19.2	18.8	18.4	18.5	18.6	11.7	13.4	14.3	16.2	16.6	17.6	17.9	18.5
12	..	27.1	14.2	24.3	21.9	20.7	18.9	18.7	18.4	18.6	18.8	12.5	14.1	14.8	16.5	16.8	17.7	18.3	18.7
13	..	29.0	10.8	25.4	22.9	21.7	19.4	19.0	18.7	18.8	18.9	12.0	13.6	14.7	16.5	16.9	17.8	18.3	18.8
14	..	29.8	12.3	25.5	23.0	21.9	19.4	19.1	18.9	19.0	19.0	13.3	14.9	15.5	17.2	17.0	17.9	18.3	18.9
15	0.01	25.6	14.7	22.2	20.8	21.1	19.1	18.9	18.9	19.1	19.2	15.6	16.6	16.8	17.6	17.4	18.3	18.7	19.1
16	0.19	23.6	15.0	21.8	20.3	19.8	19.0	19.0	19.0	19.2	19.3	15.7	16.7	16.9	18.2	18.0	18.7	18.8	19.2
17	..	24.3	14.9	22.7	21.3	20.9	19.8	19.6	19.4	19.4	19.4	15.4	16.7	17.0	18.5	18.2	18.9	19.0	19.3
18	0.74	24.3	13.8	22.7	21.3	20.9	20.0	19.8	19.7	19.7	19.7	14.7	16.1	16.3	17.9	18.0	18.9	19.3	19.6
19	0.03	19.7	14.4	19.9	19.2	19.2	18.9	19.1	19.4	19.6	19.7	15.7	16.7	16.9	18.2	18.1	18.8	18.7	19.3
20	..	23.9	9.5	24.7	22.4	21.5	19.9	19.7	19.5	19.6	19.7	12.2	13.9	14.6	16.8	17.3	18.5	19.2	19.7
21	..	23.1	8.6	22.2	20.4	19.8	18.6	18.6	19.4	19.6	19.7	10.7	12.7	13.4	15.7	16.5	17.8	18.8	19.6
22	..	24.8	9.0	22.2	20.2	19.6	18.2	18.2	18.2	18.7	19.6	11.2	12.1	13.7	16.3	16.3	17.7	18.4	19.1
23	..	25.7	10.7	22.1	20.3	19.7	18.4	18.2	18.2	18.8	19.4	12.2	14.1	14.5	16.5	16.5	17.6	18.4	19.1
24	..	27.2	13.0	23.5	21.6	20.6	19.0	18.7	18.6	18.9	19.2	13.9	15.3	15.7	17.0	16.8	17.8	18.4	19.1
25	..	29.2	13.4	23.7	21.8	21.1	19.5	19.3	19.1	19.3	19.4	14.2	15.8	16.2	17.8	17.6	18.3	18.5	19.2
26	..	29.8	11.9	25.9	23.5	22.4	20.4	20.0	19.6	19.7	19.7	13.4	15.2	16.0	17.9	18.1	18.8	19.2	19.6
27	..	28.4	11.3	26.1	23.4	22.4	20.4	20.0	19.8	19.9	19.9	12.8	14.7	15.4	17.5	17.9	18.9	19.4	19.9
28	..	26.6	11.7	26.2	23.4	22.4	20.3	20.0	19.8	19.9	20.0	13.4	15.3	16.0	17.8	18.1	19.0	19.5	20.0
Mean	26.3	11.5	24.0	21.8	20.9	19.1	18.8	18.6	18.9	19.1	12.6	14.2	14.8	16.7	16.9	17.8	18.4	18.9

March 1914.

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.															
		Max.	Min.	Maximum.					Minimum.										
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
1	..	29.6	14.3	26.2	23.5	22.6	20.6	20.3	20.1	20.1	20.1	15.5	17.2	17.7	18.6	18.3	19.2	19.6	20.1
2	..	27.3	16.7	24.2	22.7	22.3	21.1	20.7	20.5	20.4	20.4	17.0	18.3	18.7	19.7	19.2	19.8	20.0	20.4
3	..	25.9	15.6	24.0	22.7	22.4	21.4	21.1	21.0	20.9	20.7	16.2	17.8	18.4	19.8	19.8	20.3	20.4	20.7
4	0.04	25.0	14.0	22.9	21.7	21.4	20.8	20.9	20.9	20.9	20.9	15.5	17.2	17.9	19.4	19.5	20.3	20.6	20.9
5	..	26.0	11.5	25.3	23.4	22.7	21.2	20.9	20.6	21.0	21.0	13.9	15.9	16.7	18.7	19.1	20.2	20.7	20.9
6	..	26.5	11.2	25.6	23.9	22.7	21.0	20.7	20.5	20.7	20.9	13.4	15.4	16.3	18.3	16.7	19.9	20.5	20.9
7	..	28.2	12.2	25.8	23.7	22.7	21.0	20.7	20.5	20.7	20.9	14.6	16.5	17.2	18.9	18.9	19.9	20.4	20.9
8	..	29.9	14.0	26.7	24.7	23.7	21.7	21.3	21.0	20.9	21.0	15.4	17.1	17.7	19.5	19.3	20.2	20.5	20.9
9	..	31.8	15.0	27.7	25.3	24.4	22.2	21.7	21.4	21.3	21.1	15.9	17.7	18.3	20.0	19.8	20.5	20.7	21.1
10	..	32.0	15.6	28.9	26.1	25.1	22.7	22.3	21.9	21.6	21.4	16.4	18.2	18.9	20.5	20.3	20.5	20.7	21.0
11	..	33.1	16.1	29.5	26.3	25.3	23.0	22.5	22.1	21.9	21.6	16.8	18.5	19.2	20.8	20.8	21.3	21.5	21.6
12	..	32.0	15.4	29.5	26.6	25.7	23.5	22.9	22.5	22.2	21.9	16.9	18.9	19.5	21.2	21.1	21.5	21.7	21.9
13	..	33.3	15.7	30.9	27.3	26.2	24.9	23.8	23.5	22.9	22.5	17.1	19.2	20.1	21.9	22.0	22.4	22.4	22.5
14	..	33.3	15.6	31.1	27.7	26.6	24.4	23.8	23.5	22.9	22.7	15.7	18.1	18.8	21.0	21.4	22.3	22.7	22.7
15	..	29.0	13.1	29.0	26.3	25.8	23.9	23.5	23.3	22.9	22.7	15.7	18.1	18.7	20.9	21.3	22.2	22.6	22.7
16	..	28.7	12.5	29.4	26.3	25.5	23.6	23.2	23.3	22.9	22.7	15.7	18.1	18.7	20.9	21.3	22.2	22.6	22.7
17	..	31.5	12.8	28.4	25.8	25.0	23.3	22.9	23.3	22.8	22.7	15.7	18.1	18.7	20.7	20.7	21.9	22.4	22.7
18	..	32.6	15.7	29.5	26.4	25.5	23.5	23.0	22.7	22.6	22.6	17.0	18.9	19.6	21.2	20.8	21.9	22.3	22.6
19	..	34.1	20.0	30.5	27.1	26.1	23.9	23.4	23.1	22.8	22.6	20.2	21.9	22.1	21.9	21.3	22.1	22.4	22.6
20	0.07	26.3	16.7	24.6	23.2	23.3	23.4	23.2	23.5	22.9	22.8	17.6	19.5	20.2	21.6	21.5	22.3	22.6	22.8
21	..	30.8	16.6	29.2	27.0	25.9	23.8	23.4	23.2	22.9	22.8	17.2	19.4	20.0	21.7	21.7	22.4	22.6	22.8
22	..	30.9	14.4	29.4	27.3	26.4	24.4	23.8	23.6	23.2	23.0	15.9	18.2	19.1	21.4	21.6	22.6	22.8	23.0
23	..	31.7	13.8	31.6	28.1	26.8	24.5	24.0	23.6	23.4	23.2	16.0	18.5	19.3	21.5	21.5	22.6	23.0	23.2
24	..	32.6	12.4	33.8	28.0	26.2	24.3	23.8	23.6	23.3	23.2	15.6	18.0	19.0	21.3	21.5	22.6	22.9	23.2
25	..	33.8	14.4	33.0	28.6	27.1	24.8	24.3	24.0	23.5	23.3	17.1	19.5	20.3	22.2	21.9	22.9	23.1	23.3
26	..	34.6	15.7	34.2	29.7	28.0	25.4	24.7	24.5	23.7	23.5	18.2	20.4	21.1	22.8	22.4	23.1	23.3	23.5
27	..	36.2	18.4	34.6	30.5	28.8	26.0	25.4	25.4	24.1	23.7	19.4	21.4	22.0	23.4	22.8	23.4	23.4	23.2
28	..	36.4	17.2	35.9	31.5	29.7	26.7	25.9	25.6	24.5	24.1	18.9	21.3	22.1	23.9	23.6	24.0	24.0	24.1
29	..	36.3	15.6	38.3	32.8	30.8	27.4	26.6	26.1	24.9	24.4	18.6	21.2	21.8	23.9	23.9	24.4	24.5	24.4
30	..	36.1	17.7	38.1	32.8	30.7	27.5	26.7	26.3	25.2	24.7	19.8	22.1	22.7	24.5	24.2	24.8	24.8	24.8
Mean	..	31.2	14.9	29.6	26.6	25.6	23.5	23.1	22.9	22.5	22.3	16.7	18.7	19.4	21.1	21.0	21.8	22.1	22.3



May 1914.

Date.	Rain inches.	SOIL TEMPERATURE.																		
		AIR (SHADE).		Maximum.									Minimum.							
		Max.	Min.	1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"	
°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C		
1	..	34.4	22.7	43.5	40.4	38.5	35.2	33.9	32.9	30.9	30.0	26.3	28.4	28.8	30.3	30.5	30.8	30.6	30.3	
2	..	34.6	24.7	42.8	39.1	37.4	34.7	33.4	32.9	31.0	30.1	27.1	28.9	29.3	30.5	30.7	30.9	30.8	30.5	
3	..	35.5	24.5	42.2	38.8	37.1	34.2	33.2	32.9	31.0	30.3	26.2	28.2	28.6	30.2	30.4	30.9	30.9	30.7	
4	..	38.7	24.9	46.2	42.0	40.1	36.1	34.8	33.8	31.6	30.6	27.1	29.3	29.8	31.4	30.9	30.9	30.9	30.8	
5	..	40.7	23.3	49.3	43.7	42.2	37.4	36.0	36.4	32.4	31.3	27.9	29.8	30.1	32.0	31.5	32.2	31.5	31.5	
6	..	34.0	23.9	46.2	40.1	38.9	37.2	34.7	36.3	32.3	31.4	27.7	29.8	30.2	31.3	31.5	32.1	32.0	31.5	
7	..	35.8	22.8	44.8	40.2	39.2	36.6	34.7	36.2	32.3	31.4	27.0	29.2	29.8	31.3	31.8	32.0	31.8	31.8	
8	1.21	33.6	20.6	43.2	39.1	38.2	35.7	33.8	34.1	32.2	31.4	23.2	25.4	26.4	29.3	29.7	30.5	31.0	31.2	
9	..	28.2	21.1	34.3	31.9	32.2	33.0	30.7	34.0	32.0	30.4	22.2	24.4	25.1	27.3	27.6	28.6	30.0	30.7	
10	0.47	29.4	20.6	34.1	31.1	30.6	30.6	28.7	30.2	30.3	30.4	21.2	23.2	23.8	25.8	26.5	27.5	28.5	29.3	
11	..	31.9	22.4	37.4	34.5	33.3	30.5	29.5	29.7	29.0	29.3	22.5	24.3	24.8	26.5	27.1	27.8	28.5	29.2	
12	..	34.0	22.2	36.7	34.5	33.4	30.9	29.8	29.9	28.8	28.7	21.4	23.6	24.3	26.4	27.1	27.9	28.6	29.0	
13	..	36.4	21.7	36.9	34.7	33.4	31.3	30.2	30.3	29.1	28.9	21.6	23.9	24.5	26.8	27.5	28.0	28.6	29.0	
14	..	38.1	19.7	40.3	37.7	36.0	32.4	31.2	30.9	29.4	29.2	19.9	22.6	23.6	26.4	27.4	28.4	28.9	29.3	
15	..	37.2	24.3	41.2	38.6	37.0	33.3	31.8	32.0	29.9	29.3	24.9	26.7	27.2	28.9	28.5	28.7	29.2	29.7	
16	..	35.8	23.5	41.6	39.1	37.8	34.3	32.9	32.0	30.6	29.8	26.0	27.7	28.2	30.0	30.1	29.8	29.9	30.1	
17	0.05	28.7	21.8	33.8	32.6	32.2	31.1	30.9	31.1	30.5	30.0	23.5	25.4	25.9	27.7	28.3	29.1	29.9	30.2	
18	..	32.0	21.6	40.8	38.3	36.7	32.9	31.9	32.2	30.7	29.9	23.8	25.9	26.6	28.5	28.6	29.1	29.7	30.1	
19	..	36.7	22.4	42.9	40.4	39.0	34.6	33.4	32.2	30.7	30.0	25.1	27.2	28.2	29.9	30.1	29.8	30.0	30.2	
20	..	39.5	23.1	43.5	41.0	39.6	35.4	34.2	33.1	31.4	30.5	24.8	27.0	27.9	30.1	30.8	31.0	30.7	30.6	
21	..	40.3	24.5	43.5	41.1	39.8	35.6	34.5	33.2	32.3	31.4	26.9	28.9	29.7	31.4	31.9	31.3	31.3	31.1	
22	..	38.8	24.6	44.1	41.8	40.4	36.4	35.2	33.7	32.3	31.8	27.0	29.1	29.8	31.5	32.3	32.3	31.7	31.6	
23	..	38.7	24.4	44.4	42.1	40.8	36.8	35.6	34.2	32.7	31.8	28.1	30.2	30.7	32.3	32.8	32.7	32.6	31.8	
24	..	38.3	25.9	43.9	41.8	40.7	36.8	35.7	34.8	33.0	32.0	28.6	30.4	31.1	32.6	33.2	33.0	32.8	32.7	
25	..	39.2	26.5	44.8	42.7	41.3	37.9	36.3	35.4	33.8	32.7	29.0	30.9	31.5	33.0	33.6	33.4	33.4	33.1	
26	..	39.0	26.8	44.9	42.7	41.4	37.6	36.5	35.4	33.8	32.7	29.3	31.2	31.8	33.3	33.8	33.7	33.5	33.3	
27	..	39.8	26.8	44.9	42.9	41.9	37.9	37.3	35.7	34.1	33.1	29.3	31.8	32.3	33.3	33.9	34.2	33.9	33.7	
28	..	40.0	24.9	45.7	43.6	42.3	38.6	37.4	36.2	34.4	33.4	28.9	30.8	31.5	33.3	33.8	34.2	33.9	33.7	
29	..	37.4	26.7	44.6	42.6	41.5	38.0	37.1	36.2	34.5	33.6	29.8	31.6	32.1	33.7	33.9	34.3	34.1	33.7	
30	0.13	39.1	25.0	45.8	43.6	42.4	38.7	37.6	36.4	34.8	33.8	28.4	30.7	31.5	33.4	34.1	34.5	34.2	33.9	
31	..	38.0	26.0	44.6	42.7	41.6	38.1	37.3	36.2	34.8	33.9	29.0	30.9	31.7	33.4	34.1	34.5	34.6	34.2	
Mean	36.3	23.7	42.4	39.5	38.3	35.2	33.9	33.6	31.8	31.1	25.8	27.9	28.5	30.3	30.7	31.0	31.2	31.2	

June 1914.

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
		Max.	Min.	Maximum.						Minimum.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
		°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C

July 1914.

Date.	Rain. inches.	AIR (SHADE).		SOIL TEMPERATURE.															
		Max.	Min.	Maximum.						Minimum.									
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
1	0.45	32.8	25.7	36.1	35.7	35.0	34.8	35.2	35.8	35.0	34.4	27.8	29.8	30.3	32.0	32.8	32.8	33.2	33.2
2	..	29.8	24.8	31.7	32.2	31.9	32.3	32.8	33.5	33.3	34.1	26.3	27.8	28.4	30.3	31.2	31.5	32.5	32.5
3	0.94	35.4	24.9	36.7	35.9	35.5	33.4	32.8	33.5	33.2	33.4	26.5	28.0	28.7	29.9	30.5	31.5	32.6	33.2
4	1.56	33.5	24.6	36.6	35.6	35.3	32.7	32.4	32.7	32.8	32.7	26.5	28.0	28.5	29.9	30.5	31.1	32.0	32.8
5	1.56	28.0	24.3	28.9	28.7	29.1	30.5	30.7	31.8	32.3	32.4	25.9	27.1	28.0	29.3	29.9	31.0	31.6	31.8
6	0.32	31.1	24.6	34.9	33.5	33.2	31.2	30.8	30.7	31.3	31.8	26.7	27.9	28.3	29.4	29.4	30.0	30.9	31.4
7	0.31	32.1	25.4	36.5	34.5	33.9	31.9	31.3	31.1	31.0	31.1	27.1	28.3	28.6	29.6	30.1	30.3	30.9	31.4
8	0.02	32.0	25.8	35.0	33.2	32.8	31.4	30.9	31.1	30.9	31.0	26.5	27.8	28.3	29.4	30.0	30.3	30.8	31.3
9	..	33.7	27.1	36.5	34.9	34.3	32.1	31.7	31.3	31.1	31.0	27.8	29.0	29.3	30.3	30.5	30.4	30.9	31.3
10	0.28	35.9	25.1	38.1	36.7	36.3	33.5	32.9	32.1	31.7	31.3	28.3	29.7	29.0	30.6	31.1	31.4	31.7	31.9
11	..	35.3	27.3	38.3	36.4	35.7	33.4	32.8	32.6	32.0	31.7	28.3	29.7	30.1	31.3	31.4	31.4	31.7	31.9
12	..	33.9	26.1	35.3	34.4	34.3	33.0	32.7	32.4	32.2	32.0	27.2	28.5	29.0	30.5	31.2	31.6	32.1	32.3
13	0.50	32.7	25.3	34.2	33.3	32.9	32.0	31.8	32.2	32.1	32.0	27.0	28.2	28.7	30.0	30.9	31.2	31.8	32.3
14	2.12	31.6	24.6	35.5	33.5	33.0	32.2	31.9	31.9	31.9	31.9	26.1	27.0	26.8	27.8	29.3	30.2	31.3	32.1
15	1.26	30.2	25.6	31.1	30.7	30.3	30.4	31.5	31.0	31.7	31.8	27.1	28.1	28.3	28.7	28.5	28.4	28.0	28.7
16	0.03	30.6	25.4	31.5	30.8	30.7	30.3	30.2	30.6	30.9	31.2	26.5	27.6	28.0	29.0	29.5	30.0	30.7	31.3
17	0.10	32.3	25.3	32.8	31.6	31.4	30.7	30.4	30.6	30.9	31.2	26.5	27.8	28.0	29.1	29.5	29.9	30.5	31.2
18	0.14	31.8	25.6	31.8	30.9	30.7	30.3	30.2	30.6	30.9	31.2	26.7	27.8	28.1	29.1	29.5	29.9	30.4	31.0
19	0.25	31.7	25.8	32.4	31.3	31.0	30.3	30.1	30.3	30.4	30.6	27.4	28.5	28.8	29.3	29.6	29.9	30.4	30.9
20	..	33.7	26.4	33.3	32.3	32.0	30.9	30.6	30.5	30.5	30.5	27.4	28.5	28.8	29.7	29.8	30.0	30.4	30.8
21	0.01	33.3	25.7	32.0	31.4	31.3	30.8	30.6	30.7	30.6	30.6	27.0	28.1	28.5	29.8	30.0	30.0	30.3	30.8
22	0.10	32.4	25.9	32.3	31.3	31.0	30.5	30.3	30.6	30.6	30.6	26.6	27.7	28.0	29.0	29.5	29.9	30.6	31.1
23	0.01	32.7	25.6	31.2	30.3	30.2	30.1	30.0	30.3	30.5	30.6	26.2	27.5	27.8	28.8	29.3	29.9	30.4	30.9
24	..	32.5	25.0	31.4	30.4	30.3	29.9	29.8	30.2	30.3	30.5	26.1	27.2	27.5	28.7	29.3	29.6	30.0	30.8
25	..	33.2	25.7	31.1	30.3	30.2	29.9	29.8	30.1	30.3	30.4	26.6	27.7	28.1	29.0	29.5	29.7	30.3	30.7
26	..	34.1	25.7	31.8	30.8	30.5	30.2	30.1	30.3	30.4	30.4	26.8	27.8	28.2	29.2	29.6	29.8	30.3	30.8
27	..	34.9	25.8	31.8	31.3	30.9	30.5	30.3	30.6	30.6	30.6	26.9	28.0	28.4	29.4	29.7	30.0	30.5	30.8
28	..	35.9	26.3	32.0	31.5	31.1	30.8	30.5	30.6	30.8	30.8	27.1	28.2	28.4	29.6	30.2	30.3	30.6	31.1
29	..	34.0	26.2	31.3	31.0	30.7	30.4	30.3	30.8	30.8	30.9	27.2	28.2	28.5	29.6	30.1	30.3	30.8	31.2
30	..	35.3	26.2	31.4	31.0	30.7	30.5	30.4	30.8	30.8	30.9	27.1	28.2	28.5	29.7	30.0	30.3	30.8	31.3
31	0.23	33.9	25.7	31.1	30.7	30.6	30.4	30.3	30.7	30.7	30.8	26.8	27.9	28.5	29.4	29.9	30.2	30.7	31.2
Mean ..	..	32.9	25.6	33.4	32.5	32.2	31.3	31.1	31.3	31.4	31.4	26.9	28.1	28.5	29.6	30.1	30.4	30.9	31.4

August 1914.

Date.	Rain inches.	Air (shade).		Maximum.								Minimum.								
		Max.	Min.	1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"	
1	1.03	34.0	24.7	29.8	30.8	30.6	30.2	30.3	30.8	30.8	30.8	30.8	26.2	27.1	27.6	28.8	29.3	29.9	30.5	31.3
2	1.63	32.3	24.8	29.8	29.8	29.6	31.1	31.2	30.8	31.0	30.8	30.8	25.8	26.7	26.8	27.9	28.4	29.3	30.2	31.1
3	1.28	30.2	23.0	28.6	29.2	28.6	29.3	30.2	30.6	30.3	30.7	30.7	25.7	26.6	26.8	27.1	27.9	28.4	29.6	30.5
4	1.23	29.4	23.2	28.1	29.0	28.3	28.3	28.7	30.2	29.8	30.2	29.8	25.8	26.6	26.8	27.6	27.9	28.5	29.2	30.1
5	0.21	30.4	23.9	28.6	28.3	27.8	27.9	28.1	28.7	29.3	29.7	29.3	24.9	25.9	26.2	27.2	27.4	28.1	28.8	29.7
6	0.06	30.7	24.0	28.0	28.5	27.9	27.7	27.8	28.5	28.9	29.0	28.9	24.7	25.7	26.2	26.9	27.4	27.9	28.6	29.5
7	0.05	30.9	24.1	28.3	28.5	28.0	27.7	27.8	28.1	28.6	29.0	28.6	25.3	26.2	26.4	27.3	27.4	27.8	28.4	29.3
8	0.03	30.8	23.2	28.0	28.4	28.4	28.1	27.8	28.2	28.6	28.9	28.9	25.7	26.5	26.7	27.5	27.6	27.9	28.5	29.3
9	0.24	32.1	24.6	28.7	28.6	28.4	28.1	28.0	28.4	28.6	28.8	28.8	25.6	26.5	26.7	27.5	27.8	28.0	28.6	29.3
10	0.19	32.4	25.3	29.8	29.4	29.1	28.6	28.4	28.7	28.7	28.9	28.9	26.0	27.3	27.4	27.9	27.9	28.1	28.6	29.3
11	1.34	30.9	25.3	28.6	28.8	28.6	28.5	28.5	28.6	28.8	28.9	28.9	26.2	27.0	27.1	27.8	27.9	28.2	28.7	29.3
12	4.38	30.9	25.3	28.6	29.1	29.0	29.0	28.6	28.7	28.7	28.9	28.9	24.2	25.1	25.4	26.3	26.7	27.2	28.1	29.0
13	2.25	29.7	23.2	27.5	28.1	27.3	27.1	27.2	28.0	28.4	28.6	28.6	24.5	25.3	25.4	26.2	26.3	26.6	27.2	28.1
14	1.59	29.7	24.3	27.3	28.0	27.1	26.8	27.0	27.2	27.6	28.1	28.1	25.5	26.1	26.2	26.5	26.4	26.5	27.2	28.1
15	..	33.2	26.4	29.3	29.1	28.8	28.0	27.8	27.8	27.7	27.9	27.9	26.0	27.1	27.2	27.4	27.8	27.8	28.0	28.0
16	..	33.8	26.3	29.7	29.7	29.3	28.6	28.3	28.5	28.2	28.2	28.2	26.6	27.4	27.4	27.8	27.8	28.2	28.2	28.3
17	0.03	32.7	25.4	29.1	29.4	29.0	29.5	29.1	29.0	28.8	28.5	28.5	26.0	26.9	27.1	27.8	27.9	28.2	28.2	28.3
18	..	31.9	25.8	29.0	29.2	28.6	28.8	28.3	28.6	28.6	28.6	28.6	26.3	27.1	27.1	27.8	27.8	28.2	28.2	28.3
19	..	33.1	27.0	29.6	29.5	29.3	28.9	28.6	28.8	28.8	28.8	28.8	27.2	28.0	28.1	28.5	28.3	28.4	28.5	29.0
20	..	33.2	25.6	30.1	29.9	29.6	29.6	29.3	29.1	29.1	29.0	28.9	27.2	27.6	27.8	28.5	28.3	28.4	28.5	29.0
21	0.15	31.7	28.7	29.1	29.4	29.0	29.1	28.9	29.4	29.1	28.9	28.9	26.8	27.6	27.7	28.4	28.5	28.7	28.8	29.2
22	..	32.1	26.2	29.0	29.0	29.0	28.9	28.8	29.1	29.1	29.0	29.0	26.7	27.4	27.7	28.4	28.5	28.7	28.8	29.2
23	..	32.6	26.7	29.4	29.2	29.2	29.0	28.9	29.1	29.1	29.1	29.1	26.7	27.4	27.7	28.4	28.5	28.8	28.9	29.5
24	..	34.5	26.7	30.5	30.4	30.1	29.5	29.3	29.2	29.3	29.3	29.3	27.3	28.0	28.1	28.7	28.7	28.8	29.0	29.5
25	..	33.5	26.9	30.2	30.0	29.8	29.5	29.3	29.4	29.5	29.5	29.5	27.3	28.1	28.2	28.9	28.9	29.2	29.2	29.7
26	0.42	34.0	24.2	30.2	30.2	29.9	29.5	29.4	29.6	29.5	29.4	29.5	26.0	27.1	27.1	27.8	28.4	28.8	29.1	29.7
27	5.86	31.3	24.6	29.0	29.2	29.4	29.5	28.9	29.6	29.5	29.5	29.5	25.1	25.9	26.0	26.9	26.9	27.4	27.9	28.7
28	2.60	27.1	24.4	28.6	28.7	27.5	27.5	28.6	28.7	29.5	29.5	29.5	24.8	25.6	26.3	26.3	26.3	27.1	27.9	28.7
29	3.93	27.4	23.9	27.0	27.3	26.5	27.2	28.6	28.6	28.3	28.6	28.6	24.4	25.2	25.4	26.0	26.3	26.5	27.3	28.3
30	0.33	28.3	24.4	27.1	27.9	27.0	26.9	26.8	27.1	27.4	28.0	28.0	25.1	25.7	25.8	26.5	26.5	26.6	27.3	28.1
31	..	33.1	25.4	30.7	29.9	29.2	28.1	27.8	27.7	27.7	27.8	27.8	26.1	26.3	26.8	27.0	26.8	26.9	27.3	28.1
Mean ..	..	31.5	25.3	28.9	29.1	28.7	28.6	28.6	28.9	29.0	29.1	29.1	25.9	26.7	26.9	27.6	27.8	28.1	28.5	29.3

September 1914.

Date.	Rain inches.	AIR (SHADE).		SOIL TEMPERATURE.															
		Max.	Min.	Maximum.						Minimum.									
				1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
1	0.22	32.0	25.5	30.0	29.6	29.1	28.4	28.1	28.2	28.1	28.0	26.4	27.2	27.1	27.8	27.5	27.6	27.8	28.3
2	1.16	32.3	25.3	29.8	29.4	28.9	28.7	28.6	28.6	28.3	28.3	26.3	27.2	27.2	27.9	27.7	28.0	28.1	28.4
3	0.77	32.2	25.8	30.9	30.4	29.7	28.8	28.5	28.7	28.4	28.3	27.1	27.7	27.8	28.6	28.4	28.3	28.2	28.7
4	..	32.8	25.8	32.4	31.1	30.6	29.2	29.0	28.8	28.6	28.4	26.8	27.6	27.8	28.7	28.6	28.3	28.4	28.8
5	..	33.0	27.0	34.7	31.3	30.5	29.7	29.2	29.2	28.9	28.7	27.1	28.1	28.2	28.7	28.6	28.5	28.7	28.9
6	..	33.9	26.7	31.6	31.2	30.7	30.0	29.5	29.4	29.2	28.9	26.8	27.9	28.0	28.7	28.8	28.9	28.9	29.1
7	0.01	33.3	26.9	30.9	30.4	30.0	29.7	29.6	29.6	29.2	29.0	27.2	28.0	28.3	28.7	28.8	29.0	29.1	29.4
8	..	33.3	26.7	30.9	30.7	30.2	29.8	29.4	29.5	29.2	29.0	27.2	27.9	28.2	28.9	29.0	29.0	29.2	29.6
9	..	34.5	27.1	32.0	31.2	30.6	30.0	29.6	29.7	29.5	29.3	27.5	28.2	28.3	28.9	29.2	29.1	29.3	29.6
10	0.11	34.2	26.5	31.9	31.3	30.8	29.9	29.7	29.7	29.5	29.3	27.6	28.4	28.5	29.1	29.2	29.2	29.4	29.6
11	..	33.6	27.1	31.8	31.0	30.4	29.9	29.6	29.7	29.5	29.4	27.4	28.2	28.4	29.1	29.2	29.3	29.5	30.8
12	..	33.1	25.1	31.0	30.5	30.1	29.7	29.5	29.7	29.5	29.4	26.7	27.3	27.8	28.4	28.8	29.0	29.4	29.8
13	..	33.1	26.1	30.5	30.0	29.6	29.4	29.1	29.6	29.4	29.4	26.3	27.6	27.7	28.6	28.7	29.1	29.4	29.8
14	0.15	33.2	25.6	30.6	30.0	29.6	29.3	29.2	29.4	29.3	29.3	25.9	27.1	26.4	28.3	28.5	28.9	29.2	29.7
15	0.03	32.6	25.0	29.9	30.0	29.3	28.6	28.5	28.7	28.4	28.3	25.4	26.7	26.9	28.0	28.2	28.6	29.0	29.7
16	..	31.8	24.9	29.3	29.1	28.7	28.6	28.5	28.9	29.2	29.2	25.4	26.7	26.7	26.9	27.4	27.9	28.5	29.2
17	1.31	31.4	23.0	29.1	29.1	28.8	28.6	28.5	28.7	29.0	29.1	24.6	25.7	26.7	26.9	28.0	28.5	29.1	29.4
18	..	32.6	25.6	29.8	29.2	28.7	28.4	28.2	28.6	28.7	28.9	26.6	27.4	28.0	28.2	28.3	28.6	29.0	29.2
19	..	34.3	26.0	30.8	30.4	29.8	29.0	28.8	28.8	28.7	28.9	26.6	27.4	28.0	28.2	28.3	28.5	28.5	29.4
20	..	34.3	25.1	30.9	31.1	30.2	29.3	29.2	29.1	29.0	29.0	26.4	27.3	28.0	28.5	28.5	28.7	29.0	29.4
21	0.30	32.9	23.9	30.2	30.4	30.1	29.1	29.0	29.1	29.0	29.2	25.8	26.7	27.0	27.8	28.1	28.7	29.0	29.4
22	0.03	32.1	22.3	29.5	29.9	29.2	28.5	28.4	28.6	28.6	29.4	24.5	25.9	26.4	27.5	27.9	28.4	28.8	29.4
23	1.84	32.1	21.7	29.5	29.9	29.2	28.5	28.4	28.7	28.9	29.0	24.1	25.2	25.6	26.7	27.0	27.7	28.4	29.1
24	..	31.0	23.4	29.5	29.6	29.6	28.1	27.9	28.6	28.7	28.9	25.5	26.2	26.5	27.0	27.4	27.8	28.1	28.9
25	0.08	32.2	23.6	30.0	30.3	30.1	28.2	28.2	28.5	28.5	28.6	25.5	26.4	26.6	27.5	27.7	28.0	28.4	28.5
26	..	31.4	23.8	29.5	29.3	29.1	28.4	28.3	28.5	28.5	28.6	25.5	26.8	26.8	27.7	27.8	28.1	28.3	28.8
27	0.12	32.3	24.1	29.5	29.2	29.1	28.4	28.3	28.5	28.5	28.5	25.1	26.2	26.5	27.5	27.7	28.1	28.3	28.8
28	..	33.3	23.5	29.9	29.7	30.6	28.5	28.3	28.6	28.5	28.6	24.6	26.0	26.1	27.1	27.5	28.2	28.4	28.6
29	..	33.4	22.4	30.4	29.9	30.5	28.7	28.4	28.9	28.5	28.6	24.6	25.6	26.2	27.0	27.5	28.2	28.4	28.5
30	..	33.4	22.2	30.6	30.5	30.0	28.6	28.3	28.4	28.5	28.5	24.4	25.6	26.2	27.0	27.5	28.0	28.3	28.7
Mean	..	32.9	24.9	30.6	30.2	29.8	29.0	28.8	29.0	28.9	28.9	26.1	27.0	27.3	28.0	28.2	28.4	28.7	29.1

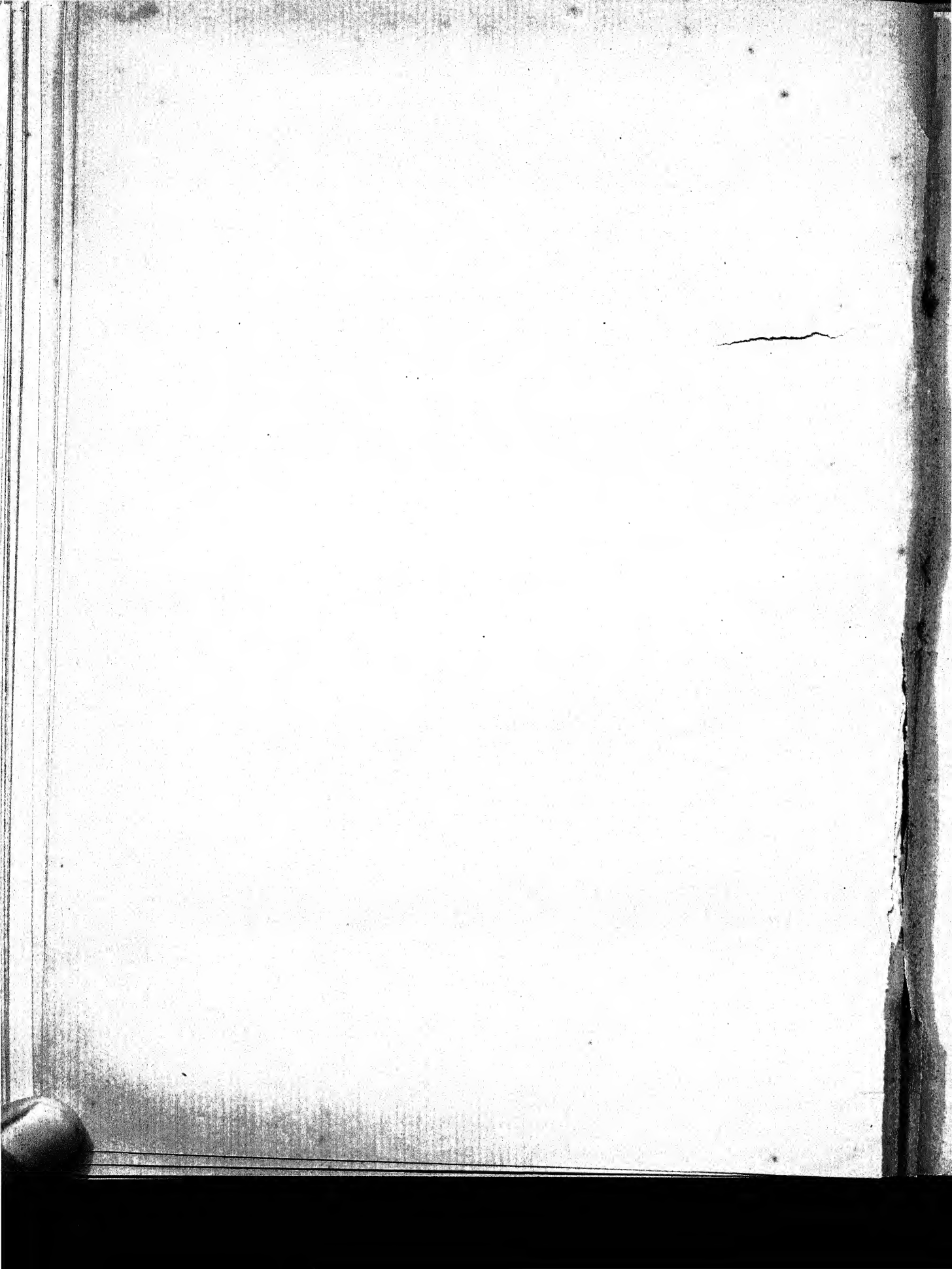
SOIL TEMPERATURES

October 1914

Date.	Rain inches.	AIR (SHADE).		Maximum.								Minimum.							
		Max.	Min.	1"	2"	3"	6"	9"	12"	18"	24"	1"	2"	3"	6"	9"	12"	18"	24"
1	..	32.9	24.4	29.6	29.8	29.1	28.3	28.0	28.2	28.5	28.5	24.1	25.1	25.4	26.6	27.1	27.7	28.3	28.7
2	..	32.7	22.4	29.2	29.4	28.7	27.9	27.8	28.2	28.4	28.4	24.6	25.4	25.7	26.8	27.0	27.6	28.2	28.0
3	..	32.4	22.0	28.2	28.8	28.8	27.5	27.5	28.0	28.3	28.3	24.1	25.0	25.4	26.7	26.9	27.2	27.9	28.3
4	..	32.3	22.6	28.5	28.7	29.7	27.5	27.3	27.8	28.0	28.2	24.2	25.2	25.6	26.8	27.1	27.3	27.8	28.3
5	..	32.4	22.7	28.5	28.8	29.0	27.5	27.3	27.7	27.9	28.0	24.7	25.3	25.6	26.6	27.1	27.3	27.7	28.3
6	..	33.3	23.4	29.0	29.1	29.1	27.5	27.3	27.4	27.8	28.0	24.6	25.7	26.0	27.2	27.4	27.5	27.7	28.3
7	..	33.0	23.8	29.4	29.6	29.9	27.9	27.7	27.8	27.9	28.0	25.0	26.0	26.3	27.2	27.5	27.5	27.7	28.2
8	..	34.1	23.3	30.4	29.8	29.8	28.2	28.1	28.1	28.0	28.1	24.7	25.9	26.4	27.4	27.5	27.6	27.8	28.3
9	0.03	31.9	19.5	29.0	29.3	29.8	27.6	27.5	28.0	28.0	28.1	22.1	23.4	24.0	25.8	26.6	27.5	27.8	28.3
10	..	31.8	21.7	28.9	28.7	27.9	27.2	27.0	27.4	27.9	28.0	22.8	23.9	24.6	26.3	26.2	26.9	27.6	28.1
11	..	32.1	20.6	29.5	29.4	28.4	27.4	27.1	27.4	27.8	28.0	22.4	23.8	24.1	24.7	25.8	26.3	27.3	28.1
12	..	33.1	19.5	29.1	28.6	28.6	27.1	27.0	27.4	27.5	27.8	21.2	22.9	23.2	25.7	26.3	26.5	27.4	28.1
13	..	31.1	18.2	28.5	28.6	27.5	26.7	26.7	27.0	27.4	27.6	21.2	22.4	23.6	25.1	25.7	26.1	26.7	27.5
14	..	31.4	19.4	28.1	28.2	27.2	26.5	26.3	26.8	27.2	27.4	22.0	23.3	23.6	25.1	25.3	25.9	26.5	27.0
15	..	31.9	19.5	27.8	28.2	26.6	26.2	26.1	26.2	26.9	27.1	22.2	23.5	23.6	25.2	25.5	25.9	26.5	27.3
16	..	32.1	20.6	28.0	27.9	27.6	26.2	26.0	26.4	26.7	27.3	21.6	23.2	23.2	25.2	25.5	25.9	26.5	27.0
17	..	30.1	19.2	28.0	27.5	27.2	26.2	26.0	26.2	26.7	27.1	22.2	23.5	23.6	25.2	25.5	25.9	26.5	27.3
18	..	32.6	18.7	28.1	28.4	27.5	26.2	26.1	26.2	26.5	26.8	21.9	23.1	23.4	24.8	25.2	25.6	26.4	27.2
19	..	32.8	17.8	28.4	27.7	27.3	26.3	26.1	26.2	26.5	26.8	21.6	23.1	23.4	24.7	25.2	25.7	26.3	27.1
20	..	31.0	14.0	27.8	26.8	26.5	26.0	25.6	26.0	26.4	26.6	18.7	20.5	21.1	23.3	24.0	24.9	25.9	26.7
21	..	30.1	14.5	26.4	25.5	25.6	24.9	24.7	25.2	26.1	26.5	18.9	20.3	21.1	22.7	23.5	24.5	25.4	26.5
22	..	29.8	15.4	25.7	24.8	24.6	24.2	24.3	24.8	25.7	26.2	18.9	20.5	20.8	22.5	23.3	24.1	25.1	26.1
23	..	29.9	15.6	25.8	24.8	24.8	24.5	24.0	24.5	25.3	25.8	19.0	20.3	21.0	22.4	23.2	23.9	24.8	25.7
24	..	30.0	16.2	26.0	25.4	24.8	24.5	24.0	24.5	25.5	26.0	19.4	20.9	21.4	22.6	23.1	23.8	24.8	25.7
25	..	30.3	17.0	26.4	25.9	25.1	24.6	24.0	24.4	24.9	25.4	19.5	20.9	21.6	22.9	23.2	23.8	24.8	25.7
26	..	30.2	17.2	26.5	26.2	25.2	24.6	24.1	24.4	24.7	25.3	19.6	21.0	21.6	22.6	23.2	23.8	24.8	25.7
27	..	30.4	16.7	26.5	26.1	25.3	24.3	24.0	24.4	24.7	25.3	19.5	20.9	21.4	22.8	23.2	23.8	24.8	25.7
28	..	30.3	16.6	26.1	25.8	25.2	24.2	23.9	24.4	24.6	25.1	19.5	21.0	21.3	22.7	23.2	23.7	24.5	25.3
29	..	30.7	16.4	26.0	26.4	25.0	24.4	24.0	24.3	24.6	25.1	19.5	20.8	21.4	22.7	23.2	23.7	24.4	25.2
30	..	30.9	17.1	27.0	26.4	25.7	24.4	24.0	24.3	24.6	25.0	19.7	21.1	21.5	22.7	23.2	23.8	24.4	25.1
31	..	30.9	17.1	27.0	26.4	25.7	24.4	24.0	24.3	24.6	25.0	19.7	21.1	21.5	22.7	23.2	23.8	24.4	25.1
Mean	31.6	19.2	27.9	27.7	27.2	26.2	26.0	26.3	26.7	27.0	21.7	23.0	23.4	24.7	25.2	25.7	26.3	27.0

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SOIL GASES

BY

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INTRODUCTION.

SOME years ago, after designing the soil-sampling tool which was described in Memoir, Vol. I, No. 6 of this series, I endeavoured to add an attachment by the aid of which the gases could be pumped out of the undisturbed soil enclosed in the cylinder. Hitherto samples of the gases contained in soils have been obtained by investigators by aspirating through a tube which had been inserted into the soil, and it is evident that under such circumstances contamination with common air would be probable; in any case the precise source (*i.e.*, depth) from which such gas specimens are derived would be uncertain, and the estimation of the volume of gas per unit volume of soil would not be possible. If, however, the gases included in the small cylinder of undisturbed soil, which my boring tool withdraws from the land, could be separated, its volume could be compared with that of the soil, the exact position with reference to depth would be known, and contamination with outside air would be excluded.

It was, however, not an easy matter to devise a suitable attachment, and although one was made several years ago, experience with it showed that it included certain defects. It was only about a year ago that the difficulties were finally overcome, and the apparatus, which is described in the first section of this memoir, designed and made.

Having succeeded in this, the apparatus was employed to obtain more definite information than we possess in relation to specific agricultural conditions such as, the gases present during the decomposition of green manure, the gases of swamp rice soil, the assimilation of nitrogen by *Papilionaceæ*, the gases present near the roots of crops, changes during nitrification.

Another question readily presented itself, namely, would it be possible to determine in a given case whether oxygen or nitrogen had been set free or

combined? It is evident that the mere analysis of the gases would not answer this question, for although in the event of finding a large increase in the amount of carbon dioxide and an approximately corresponding decrease of oxygen, the conclusion would be admissible that the oxygen had been simply utilized in an oxidation process, still this is a mere assumption, and in other possible cases the percentage composition would only show changed proportions of oxygen and nitrogen, but would not admit of a conclusion as to whether the one gas had been liberated or the other assimilated. There was one possible means of solving such a question, namely, the estimation of the argon. Since argon takes no part in animal or plant economy,¹ its ratio to the oxygen or nitrogen in soil gases would show definitely whether there is in the soil a higher or a lower ratio than in the atmosphere, and thereby provide an answer to the foregoing question. Considerable time was therefore spent in devising the most suitable means of estimating this element with sufficient precision for the purpose, when operating with comparatively small amounts of gas. The amount of argon has not, I believe, been estimated hitherto in such small volumes of gas as are referred to in this contribution. It seems therefore desirable to set out a number of the details of manipulation which I have found useful in order to reduce as far as possible the error in its determination.

Having obtained information regarding the composition of soil gases under these various conditions, attention was directed to the rate of diffusion of gases out of and into the soil in order to form an estimate of the quantities involved, and this forms the subject of the later paragraphs.

I wish to take this opportunity of expressing my obligations to my friend, Mr. W. H. Harrison, Agricultural Chemist to the Government of Madras, for kindly supplying me with samples of the gases of swamp rice lands (a subject which he has had under investigation² for several years), in order that I might determine the proportion of argon in them; also to Dr. F. P. Harrison, of the Indian Educational Service, for kindly criticism of the paragraphs regarding diffusion.

Since writing the manuscript of this memoir, the contribution on soil gases by Russell and Appleyard³ has appeared. The methods employed,

¹ MacDonald & Kellas, *Proc. Roy. Soc.*, 1895, 57, 490.

² *Mem. Dept. Agri. Ind., Chem. Series*, Vol. III, No. 3, and Vol. IV, No. 1.

³ E. J. Russell & A. Appleyard, The atmosphere of the soil; its composition and the causes of variation. *Jour. Agric. Sci.* (1915), VII, 1.

as also the objects in view at Pusa and at Rothamsted respectively, have been so different that in a great measure the information provided is hardly comparable. But one or two points seem to be definite; (i) the soil in India generally or often contains much more carbon dioxide than soil in England, (ii) in both countries a considerably larger amount of oxygen passes into combination within the soil than is accounted for by the carbon dioxide produced.

Russell and Appleyard employ the term "soil atmosphere" or "soil air" to represent what is actually the gaseous phase in the soil. In my view it is a mistake to employ the term "atmosphere" or "air" in this case. It is true that one speaks of the "atmosphere" of mines, of caves, or of underground chambers, but in each of these cases the gas mixture is either suitable for humans or is artificially made so, whereas the gaseous mixture in the soil is often (at least in India) so different that a humanbeing could not exist in it, whilst plants flourish. It is moreover a gaseous mixture which is constantly suffering changes in part by chemical or biological agency, in part according as there is much or little water present.

Another recent contribution bears indirectly on the subject of soil gases in their relation to plant life. Messrs. Briggs & Shantz,¹ when determining the amount of water transpired by farm crops, grew the plants in jars of earth which were entirely sealed over with wax, that is, these plants grew to maturity under conditions approaching "no aeration." This evidence is entirely at variance with popular ideas regarding soil gases and illustrates how little is known at present regarding the subject.

APPARATUS AND METHODS EMPLOYED.

Apparatus for the abstraction of soil gases.—As has been briefly mentioned, the newly designed apparatus for the abstraction of soil gases consists of a suitable attachment to my soil-boring cylinder. A section of the iron cylinder is shown at A in fig. 1. In order to obtain the soil specimen, this cylinder, attached to a shaft, is forced into the ground, aided by a rotating motion, and after sinking to the required distance, withdrawn. The soil comes out of the bore-hole intact, both upper and lower faces being smooth or approximately so. The problem was to devise a means of enclosing this soil specimen in such a manner that the contained gases could be pumped out.

¹ Briggs & Shantz, Relative water requirement of Plants, *J. Ag. Research*, III, p. 1 to 63.

Among the several means which were tried with this end in view, one may be mentioned because it was employed for some time. The *upper* soil-surface in the cylinder was sealed by pouring molten Wood's alloy (m.p. about 80°C.) on to it. This seal was not perfectly tight after solidifying, but was made so by the addition of a layer of molten paraffin wax. The lower soil-surface was closed by passing a rubber cap over that end of the cylinder. The rubber cap was provided with a tube to which a glass tube and stop-cock could be attached. This method included two defects. Firstly, there was a difficulty in obtaining rubber caps to fit the cylinders sufficiently well; they could not be made in India and those obtained from Europe were frequently faulty. Secondly, although the temperature of the Wood's alloy was not very great, still the temperature of the soil was found to rise so seriously that improvement in this respect was desirable. Eventually the stopper and cap which are illustrated in fig. 1 were designed. The cap C which seals the lower soil-

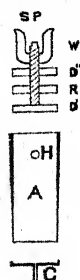
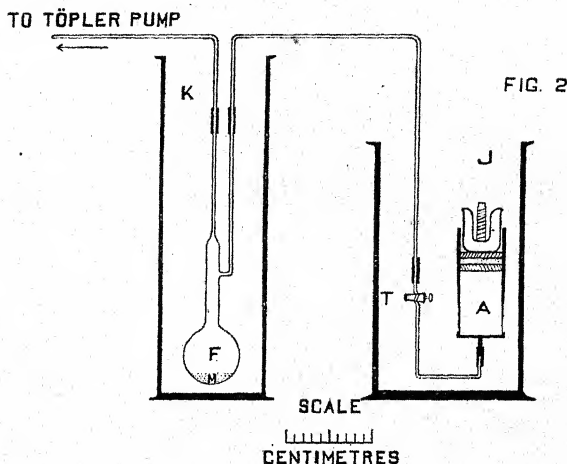


FIG. 1

surface, is of iron and its side is ground to fit the lower end of the cylinder A. It is provided with a small outlet tube of about 1 mm. bore. If this cap is dipped into molten paraffin and then pushed on to the cylinder, the edges are quite gastight. The screw-plug S.P. which seals the upper soil-surface, consists of a rubber disk R which is compressed between the iron discs D', D'', by means of the winged-nut W working on the screw. If this stopper with the screw relaxed, is placed inside the cylinder and then screwed tight, it also makes a perfect joint. When taking a soil specimen for gas analysis, the following procedure is adopted. A small flat dish of paraffin is heated. The cylinder is then forced into the soil at the required depth. Should this not be the surface soil, the soil above that which is required is first removed by other cylinders. Immediately on withdrawing the desired portion, the rubber stopper is placed, temporarily loose, in the cylinder; the lower cap is momentarily placed, inverted, in the molten paraffin so as to coat the edges only, and then pushed on to the cylinder; the soil is now substantially enclosed. The stopper is now screwed tight. To do this a T shaped box-wrench is placed on the upper end of the screw and turned against the winged-nut W, by which means the stopper is made gastight. In order to seal the edge of the lower cap more effectively, molten paraffin is applied to the edge by means of a brush. Finally in order to close the capillary outlet tube a rubber cap is passed over it. The whole procedure occupies a few seconds, and the two soil-surfaces are exposed to the air only momentarily. The cylinder or cylinders are then removed to the laboratory.

In order to remove the gases, the apparatus which is illustrated in fig. 2 has been employed. To the cap of the soil cylinder is attached a capillary tube with tap T, and it is suspended in the glass jar J. The capillary tube is attached in turn to the flask F which stands in the glass jar K, and F is in turn attached to a Töpler pump. Flask F contains a small amount of mercury M to prevent it floating. Jar J is filled with cold water so as to submerge the cylinder A; jar K is filled with ice-cold water. All the several rubber connections are thus sealed under water. The object of using ice-cold water in jar K is to prevent water accumulating in the pump. So soon as the connections are made (tap T being closed) the apparatus is exhausted as far as tap T. Subsequently T is opened and the soil gases flow into the pump section, and may be collected at the pump outlet in a suitable gas-holder. The moisture in soils, more particularly when they are wet, offers a certain amount of resistance to the flow of a proportion of the gases, and on this account after most of the gas has been removed and the vacuum has become fairly good, warm water is added to jar J in order to raise its temperature to about 45°C. This naturally occasions the expulsion of the greater part of the water in the soil, and it is principally on this account that the cooled flask F is so useful. By the aid of the cold water in K most of the water vapour in the gas becomes condensed, and, since the temperature of the gas rises as it flows into the pump, condensation of moisture in the pump is avoided.



This apparatus has been found to fulfil its function very well; it is expeditious and has offered no inconveniences. The time required to separate the gases from a portion of soil usually occupies from $1\frac{1}{2}$ to 2 hours.

Estimation of hydrogen and hydrocarbons.—After removal of the carbon dioxide and oxygen, any hydrogen or hydrocarbon present must be determined, for these are not infrequently present in soil gases. To this end I have passed the gas over hot copper oxide as being more suitable than combustion in oxygen when the percentage of these gases is quite small.

It is perhaps well to refer here to the errors accompanying an operation such as the determination of small amounts of hydrogen. In Table X small percentages of hydrogen gas are stated to have been found in the neighbourhood of plant roots, and moreover this gas was not always found. For example, hydrogen (1.39%, 1.37%) was found near the roots of maize on the 6th and 8th September and none on 10th September, and the question naturally arises how far experimental error may be answerable either for the detection of the gas, or for its total absence. If hydrogen was being formed on the earlier dates, it is improbable that the process was entirely suspended on the later date. In some cases the same gas was passed over hot copper oxide a second time, and here we have the two measurements of the gas which should be equal; any difference is due to error. Again in other cases no hydrogen was found and any difference between the gas volume before and after the operation is due to error.

The probable error deduced from such measurements = ± 0.045 c.c. the total volume of gas being about 50 to 60 c.c.; the probability is 25 : 1 that any difference after passage over copper oxide greater than 0.15 c.c. is a real difference.

Thus :

Samples of gas from neighbourhood of maize roots.

(i) Volume of gas after removing CO_2 & O	..	53.14	c.c.
Do. after passing over CuO	..	52.22	„
<hr/>			
	Δ =	- 0.92	„
<hr/>			

Do. after again passing over CuO .. 52.23 „
0.92 is a real difference due to hydrogen.

(ii) Volume of gas after removing CO_2 & O	..	42.16	„
Do. after passing over CuO	..	42.07	„
<hr/>			
	Δ =	- 0.09	„
<hr/>			

0.09 is possibly due to experimental error,
but as the gas was one of a series in which
hydrogen was usually present, the pre-

sumption is that this gas was actually present here.

(iii) Volume of gas after removing CO ₂ & O	..	54.02 c.c.
Do. after passing over CuO	..	54.07 „
$\Delta = +$		0.05 „

Here the difference is obviously due to experimental error.

Sample of gas from green-manured land.

(iv) Volume of gas after removing CO ₂ & O	..	63.76 „
Do. after passing over CuO	..	63.60 „
$\Delta = -$		0.16 „

This difference is so much greater than the probable error that the probability is 25 : 1 that hydrogen was present.

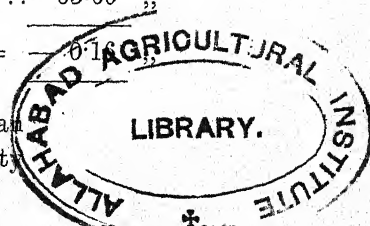
The estimation of argon.—The correct estimation of argon offers no difficulties provided the volume of gas employed is considerable, but since I have not found in the literature any example of the determination of argon in small quantities of gas, such as are obtainable from soil by my apparatus, it will be of interest to others who may be engaged on the examination of soil gases, if the apparatus and *modus operandi* which I have employed are described in some detail.

The burette.—The gas-burette consisted in the upper part of a tube of about 4 mm. internal diameter by about 30 cm. long; this was marked at each centimetre. 1 cm. = 0.15 c.c. approximately. The lower part of the burette consisted of a series of bulbs of approximately 3, 6, 12, 24 and 48 c.c. respectively, and the total volume was about 100 c.c.

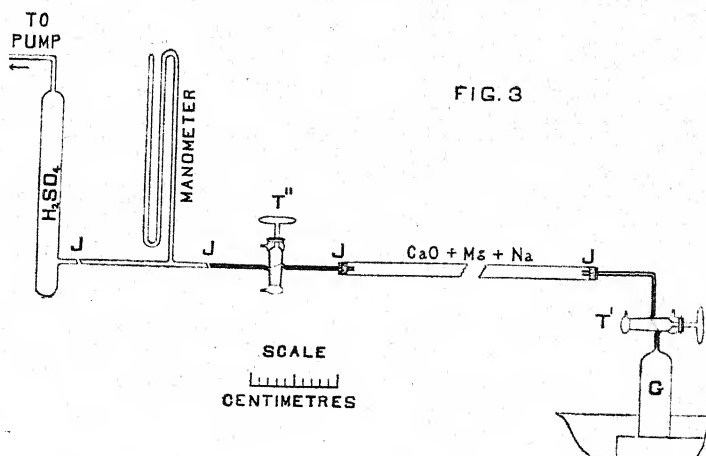
Absorption of the nitrogen.—With considerable quantities of gas, the apparatus which was employed by Rayleigh and Ramsay¹ for the separation of argon from air or that used by Schloesing,² possesses the great advantage of causing the gas to pass repeatedly over the absorbent. But when working with the small amount of gas that was obtainable from small soil specimens,

¹ *Phil. Trans.*, 1895, Vol. 186, part 1, p. 212.

² *Compt. rend.*, 1895, 121, 525.



this apparatus proved unpractical. After trial of several different arrangements, that which is illustrated in fig. 3 proved to be the best. Little expla-



nation is required. A mixture of good calcium oxide, magnesium and sodium is placed in the tube and kept in position by asbestos plugs. G is a small gas-holder full of mercury. Both taps T', T'', as likewise all rubber junctions J, J, are mercury sealed. The tube marked H_2SO_4 contains pumice saturated with sulphuric acid. When carrying out an absorption, the air is first removed from the apparatus as far as tap T'. The lime-magnesium-sodium mixture is now heated to dull redness by a small furnace (not shown) and most of the hydrogen which is evolved is removed. Tap T'' is now closed. The residual gas, nitrogen and argon, is passed into the gas-holder G, and allowed to flow into the absorption tube. The nitrogen is absorbed very rapidly at a dull red heat, but since the first portion of the gas flows very quickly over the heated lime-magnesium-sodium, it is desirable to pass the gas over the absorbent repeatedly. To this end T'' is momentarily opened and then closed again. This allows a part of the residual gas to flow into the pump section. It is pumped out into a small tube and returned to the gas-holder G, whence it is allowed to re-enter the absorbing tube. After repeating this operation four or five times, the residual argon *plus* hydrogen is pumped out, and the hydrogen is subsequently removed by passing the gas over hot copper oxide.

The perfection of the absorption of the nitrogen, and thereby the accuracy of the argon determination, will be considered presently. There are, however, a number of details of manipulation which have been found to be necessary or desirable, and these may be here suitably considered.

(a) *The lime* has been obtained by heating good marble, broken to fragments of about 2 to 3 mm. diameter and containing not more than about 2 to 3% of carbonate.

(b) *The magnesium* has been in the form of a powder. It contains a small amount of hydrogen, but the mixture of magnesium, sodium and lime yields a much larger amount. This is apparently due to the action of the sodium on the lime, which almost necessarily contains a small amount of hydroxide, and to the presence of moisture in the magnesium powder. For example :—

		c.c.
(i)	Hydrogen obtained from 1 grm. magnesium ..	2.01
(ii)	Do. from 5 grm. lime <i>plus</i> sodium ..	32.72
(iii)	Do. from 5 grm. lime, 1 grm. magnesium and sodium ..	56.88

A small amount of carbon dioxide (about 3 c.c.) was evolved from the lime at the same time. The hydrogen commences to be liberated at a low temperature and the greater part is rapidly evolved, but the last portion of the mixture of $\text{CO}_2 + \text{H}$ is not readily removed in any reasonably short time. By keeping the pump in action for $\frac{1}{2}$ —1 hour while the tube is at a dull red heat, the pressure is reduced to between 1 and 2 mm. and any hydrogen or carbon dioxide then remaining is of no consequence.

(c) *The mixture* employed is that recommended by Hempel, namely, 5 grm. calcium oxide, 1 grm. magnesium and 0.25 grm. sodium. The two former are weighed roughly and a suitable piece of sodium is measured by the eye, but cut clean under petrol. The two first named constituents are mixed rapidly in a tube; about one-half is introduced into the combustion tube, then the sodium (wiped free from petrol) is introduced, and finally the remainder of the lime-magnesium. A second asbestos plug is inserted, the tube fitted into its place in the apparatus and the air removed. These operations are performed as rapidly as possible, because it is of more importance to avoid unnecessary contact with the air, than to secure precise proportions of the ingredients. Hempel states that the quantities mentioned will absorb 326 c.c. of nitrogen, and the mixture certainly absorbs one-fourth of this quantity very perfectly.

(d) Before commencing to fill the combustion tube it is necessary that the gas-holder G shall be full of clean mercury up to and including tap T'; it is also desirable to have the pump-section from T'' exhausted, because in this case, most of the air of the combustion tube can be removed immediately after connecting it, by opening tap T''.

T. Schloesing¹ found, in a series of analyses of air in the neighbourhood of Paris, in which he employed about 1.5 litres of air for each analysis, from 0.9325 to 0.9369%A. In another series of samples of air taken at various places and elevations 1.192 volume of argon was found per 100 volumes of N+A, which is equivalent to 0.9425%A on the assumption of a normal percentage of nitrogen in the air. Kellas² found almost identical amounts.

It is evident therefore that about one-half of the percentages of argon found by my analyses are too high, a circumstance which is doubtless due to small amounts of nitrogen having escaped absorption by the CaO+Mg+Na mixture. None is too low. Considering the small amounts of gas employed the determinations are probably as accurate as one can expect.

The $\frac{N}{A}$ ratio derived from Schloesing's data is 83.2.

PROPORTIONS (BY VOLUME) OF WATER AND GASES IN THE SOIL.

It will be evident that not only can the gases of a known volume of soil be extracted, but that also from the weight of fresh soil taken in the cylinder and, subsequently, the weight and sp. gr. of the dry soil material, the volumes of the three constituents—soil-material, water and gas—can be separately deduced. When making the calculations, that part of the carbon dioxide which is present in solution (see p. 100, of this memoir) must be deducted. The following examples may be suitably quoted:—

Soil depth.	2' 6"—2' 9"	3"—6"	12"—15"
	gram.	gram.	gram.
(a) Cylinder, etc., <i>plus</i> damp soil	1082.2	1060.7	1068.0
Cylinder, etc. ..	852.5	852.4	840.2
Damp soil <i>plus</i> wax ..	229.7	208.3	227.8
Wax	0.8	1.3	1.1
Damp soil	228.9	207.0	226.7
Dry soil	207.7	193.8	209.8
Water	21.2	13.2	16.9
(b) Soil material D = 2.71	c.c. 76.64	c.c. 71.51	c.c. 77.42
Water	21.2	13.20	16.9
Gas at soil temp. and moist	59.38	68.79	61.62
	157.22	153.50	155.94
Volume of fresh soil ..	154.4	154.4	154.4

¹ *Comp. rend.* 1895 **121**, 604 and 1896, **123**, 696. | ² *Proc. Roy. Soc.* 1895, **59**, 66.

Condensed gas.—The difference between the sum of the estimated constituents and the volume of fresh soil is only small; usually the former is greater by 0.5 to 2.0 c.c. and indicates a small condensation of gas on the soil particles, but this fact is not very well established because an error of $\frac{1}{32}$ inch in measuring the length of the soil column is equal to rather more than 2 c.c. in my apparatus. The volume of such condensed gas in the Pusa soil is certainly less than 4 % of the total gas present.

Gas compressed by surface tension.—One factor which may in places operate on the volume of gases in soils is surface tension. Suppose a bubble of gas to be surrounded by water in some small cavity in the soil, the circumstances being that the quantity of water is so large that it is free to enter or leave the cavity. Under such circumstances the tension of the water—gas surface would tend to increase the pressure on the gas beyond that generally existing in the soil and which is approximately that of the atmosphere. This subject has not I think been referred to by others when discussing the physical properties of soils, and although no direct experimental data can be offered here, the matter is deserving of consideration, because quite small spheres would be exposed to considerable excess of pressure, and the corresponding decreased volume would be included in the difference between the volume of gas estimated and found, and would not be differentiated from gas condensed on the surface of soil particles in the foregoing method of measurement.

Although it is not possible to state the conditions with any great precision, the following limitation seems to be reasonable. In order that the water in any particular cavity may be free to exert its surface tension, its quantity must be considerable. It would not be sufficient for the cavity to be merely lined with water, with water-films closing its various mouths, because in such circumstances the surface tension would be as frequently negative as positive with respect to the enclosed gas. Considering various shaped cavities it seems doubtful whether the enclosed gas would possess the spherical shape and be surrounded by water sufficiently free to exert the full force of the surface tension unless the volume of water were at least twice that of the gas. Considering the relative volumes of water to gas in the Pusa soil generally, such a high proportion of water only occurs during the wettest weather and then only for a comparatively short time. Usually it may be said that, in this soil at least, the proportion of water to gas is so low that no large part of the gas could be present in the form of spheres surrounded by water sufficiently free to exert the pressure which we are now considering. Generally over the greater part of the year the major part of the gas must be free from this influence.

But here and there in the soil at any time, and more generally during the monsoon a part of the gas will be present as small spheres, and the increased pressure to which such gas would be subject is of interest. The pressure is represented by the equation :

$$p = \frac{2 T}{r}$$

in which

p = pressure

T = surface tension

r = radius of sphere

It is evident that for very small spheres the pressure becomes considerable.

In the absence of direct measurements, the size of soil cavities is unknown, but they cannot generally have a smaller diameter than the average diameter of the soil particles, and probably such cavities are generally larger than this. The average diameter of the greater part of the Pusa soil particles varies from 0.0008 to 0.0032 cm. If it be assumed that the corresponding cavities include about half their volume of gas in the form of a sphere, the radius would lie between (about) 0.0003 and 0.0012 mm.

For temperature = 30°C, $T = 71$ dynes, and the increased pressure to which such spheres as those indicated would be subjected, lies between 470,000 and 120,000 dynes, or say between one-half and one-tenth atmosphere.

Volumes of water and gas.—A number of measurements of the soil constituents at different depths and at different seasons have been made, and Table II includes some examples. Regarding the volume occupied by the soil material this is usually in the neighbourhood of 50% and varies from 45 to 55% of the total. As this is comparatively constant whilst the proportions of water and gas vary within wide limits, only the latter are set out in the Table. It will be seen that the data contained in the first two columns refer to the state of the soil after long periods of practically dry weather. Then in June the effect of the monsoon rainfall becomes evident. The first rain is absorbed by the upper soil and the third column contains an example showing how so heavy a fall as 5.5" in one week has not altered the proportion of water and gases materially in the third foot. In the same month, after a further fall of 5.3" of rain in two weeks, the water has descended into the fourth foot. Later, during the same monsoon, the proportion of water increased somewhat and that of gases was reduced. The effect of continuous heavy rains for two months, was to reduce the percentage volume of gases from 35 or 40% in the hot weather to between 25 and 30% in the middle of July.

Proportions (by volume) of water and gases in the soil.

Depth	1907		1911		1911		1911		1911		1911		1907		1908		1908	
	May 23rd to 27th.		May 23rd to June 2nd.		June 8th to 15th.		June 27th to 29th.		July 12th to 15th.		July 18th to 20th.		December 21st to 24th.		January 3rd to 7th.		January 8th to 11th.	
	Water %	Gas %	Water %	Gas %	Water %	Gas %	Water %	Gas %	Water %	Gas %	Water %	Gas %	Water %	Gas %	Water %	Gas %	Water %	Gas %
0"-3"	12.0	35.6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3"-6"
6"-9"
9"-12"
1' 0"-1' 3"
1' 3"-1' 6"
1' 6"-1' 9"
1' 9"-2' 0"
2' 0"-2' 3"	16.4	30.3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
2' 3"-2' 6"
2' 6"-2' 9"
2' 9"-3' 0"
3' 0"-3' 3"	6.9	45.3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3' 3"-3' 6"
3' 6"-3' 9"
3' 9"-4' 0"
4' 0"-4' 3"
4' 3"-4' 6"
4' 6"-4' 9"
4' 9"-5' 0"
5' 0"-5' 3"	21.4	22.7	20.2	22.6	19.2	25.3	..	..	..	..	..	..	..	..	..	..	..	..

Notes of rain-falls.

Feb. 5th to 7th 1.1"; March 11th to 12th 0.6"; March 16th to 18th 1.0"; otherwise no rain fell during the preceding 7 months.

January 27th 0.25"; March 2nd 0.33"; April 21st 0.34". Total rain after Novr. 1st to date of sampling was 1.42".

5' 5" of rain in one week which had been absorbed by the upper 2 ft. of soil and had not affected the 3rd foot.

After 5' 3" of rain in two weeks.

After 5' 5" of rain in two weeks.

After 3' 5" of rain in four weeks.

Monsoon rainfall ceased Sept. 24th after which there was no rain.

No rain subsequent to Sept. 24th.

No rain subsequent to Sept. 24th.

These figures refer to one class of land, the Bihar alluvium, and one cannot say what the corresponding proportions would be in other soils, but as there is extremely little information on this subject in the literature, the data will be of interest. It should also be noticed that although the volume of water increases during the rains to something like four times as much as in the dry season, the volume of gas does not generally decrease to one-half.

It will be a convenience for certain calculations to note that the percentage figures quoted in Table II, when multiplied by ten, become c.c. per c.dm. of soil.

PROPORTION OF THE GASES DISSOLVED IN THE SOIL-WATER.

It is evident that when the enclosed portion of soil is subjected to the vacuum as explained on page 89 of this memoir, not only will the gases which are present in the gas phase be pumped out, but also those which are present in the dissolved state in the aqueous solution will be extracted. Of the gases which are commonly present only one, carbon dioxide, is dissolved to any material degree. By way of illustration in respect of the other gases a high proportion of water may be assumed, *i.e.*, a condition when the amounts of dissolved gases are comparatively large. The soil interspace may be assumed as occupied one-half by water and the other half by atmospheric gases, carbon dioxide being excluded. Then :

	Vol.	O	N	A
(a) gas phase	1	20.93	78.10	0.937
(b) water	1	0.00607	0.0122	0.000337

from which it is evident that the amounts of O, N and A present in the soil-water are negligibly small. Carbon dioxide is much more soluble and is dealt with in the next paragraph.

The distribution of the amounts of CO₂ in solution and in the gas phase respectively.—A part of the carbon dioxide which is found in the mixed gases as obtained from soils is derived from the soil solution, the remainder being in the gas phase. The former is usually considerably greater than the latter, and it follows that to state the percentage of CO₂ present in the extracted gases without making due allowance for that part which is present in the soil solution would lead to a misapprehension as to the real state in the soil. For example, the analysis of a gas was found to be :—

N + A	..	.. 83.06 per cent.
O	..	.. 10.18
CO ₂	..	.. 6.76

but calculation showed that of the 2.34 c.c. CO_2 which was measured, 1.965 c.c. was present in the soil solution, and only 0.374 c.c. was in the gaseous state. Consequently the real composition of the soil gases was:—

		%
N + A	..	88.06
O	..	10.80
CO_2	..	1.14

In order to be able to calculate the proportions of carbon dioxide in solution and in the gaseous state respectively, the following information is required:—

- (i) The amount of aqueous solution in the soil and the solubility of carbon dioxide in this solution.
- (ii) The volume of the gas phase.
- (iii) The volume of CO_2 (total).
- (iv) The relation between the partial pressure of CO_2 in the gas phase and in the solution.
- (v) The temperature.

The mode of calculation involves two assumptions. The first is that the dissolved carbon dioxide is chiefly present as calcium bicarbonate. This involves no large error because calcium carbonate is the only carbonate which good soils contain in material quantity. The amount of alkali carbonates is usually so small that they cannot affect the question, and according to some recent work, magnesium carbonate is probably never present in material amount in good land.¹ Moreover calculation, to which reference is subsequently made (p. 106), shows that all ordinary soils contain much more than sufficient calcium carbonate to unite with any carbon dioxide which may be present in the soil.

The second assumption is that the carbon dioxide unites with calcium carbonate as quickly as the gas is formed. It would, it is true, be incorrect to speak of a state of true equilibrium occurring between the three phases for two reasons. (i) The aqueous solution must be assumed to be constantly moving from one point to another, either to supply a growing plant, or to replace water which has evaporated at the surface, or it is draining downward during wet weather. The actual distance through which such movement takes place is however small from the point of view now under

¹ J. Walter Leather & Jatindranath Sen. The system magnesium carbonate, calcium carbonate, carbonic acid, water. *Memoirs Dept. Agri. Ind., Chem. Series*, Vol. III, No. 8.

W. H. MacIntyre. The non-existence of magnesium carbonate in humid soils. *Agri. Expt. Station of the University of Tennessee Bull.* 107, June 1914.

consideration ; for example, the aqueous liquid probably never moves 0·5 inch per hour even in the wettest weather and usually the distance is very much less. (ii) Those gases such as carbon dioxide which are not at the same partial pressure in the soil as in the atmosphere, must be constantly subject to the process of diffusion, and consequently their quantity is always changing in the soil. Moreover it is probable that carbon dioxide is being formed over a large part of the year. But the fine state of sub-division and consequent great surface of contact between gas, water, and soil ensures that a state approaching equilibrium between the carbon dioxide and calcium carbonate must occur.

The relation between the partial pressure of the CO_2 gas and the CO_2 in $\text{Ca}(\text{HCO}_3)_2$ solution is known¹ and the following Table III contains the data necessary for our present purposes.

The volume of the liquid phase may be assumed equal to that of the water, but that of the gas phase is less than the volume of gases extracted, by the amount of carbon dioxide in solution.

TABLE III.

The relation between the carbon dioxide dissolved in $\text{Ca}(\text{HCO}_3)_2$ solution and the superincumbent gas phase.

CO ₂ per 100 c.c. gas. p.p.	c.c. CO ₂ per 100 c.c. Ca (HCO ₃) ₂ solution.		
	t = 20 °C.	t = 25 °C.	t = 30 °C.
0·1	1·31	1·35	1·39
0·2	2·01	1·97	2·04
0·3	2·59	2·57	2·55
0·4	3·10	3·04	2·99
0·5	3·57	3·47	3·39
0·6	3·98	3·85	3·74
0·7	4·38	4·22	4·07
0·8	4·77	4·57	4·38
0·9	5·13	4·83	4·68
1·0	5·45	5·19	4·97
1·5	6·99	6·57	6·22
2·0	8·42	7·77	7·28
3·0	10·80	9·84	9·09
4·0	12·95	11·66	10·60
5·0	14·85	13·30	12·05
6·0	16·60	14·78	13·33
7·0	18·30	16·15	14·50
8·0	19·90	17·50	15·63
9·0	21·35	18·70	16·67

¹ J. Walter Leather and Jatindranath Sen. The system calcium carbonate, carbonic acid, water. *Memoir Dept. Agri. Ind., Chem. Series*, Vol. I, No. 7.

The calculation for the distribution of the CO_2 between the two phases is then as follows:—

Put a = volume of water or aqueous solution

x = volume of CO_2 in unit volume solution

b = volume of gas phase

y = volume CO_2 in unit volume gas phase

then $x : y$ = ratio of CO_2 in unit volume of liquid and gas phase respectively (1)

and $ax + by$ = total volume CO_2 (2)

There are thus two unknowns, and equation(2) can only be solved after the solution of equation(1). But there is no direct solution for the latter. It can, however, be approximated; equation(2) can then be solved. From the information thus obtained a second approximation for equation(1) can be made and thence a second solution for equation(2). The true values of x and y can thus be obtained by a series of approximations. An example will illustrate the method:—

Volume of siliceous matter	..	..	82.6 c.c.
Do. water	..	..	38.0 c.c.
Do. gas	..	..	35.6 c.c.
Do. CO_2	..	..	2.34 c.c.

Temperature 30°C .

The first operation is to guess a first solution of equation (1). The CO_2 , 2.34 c.c., is distributed between the 38 c.c. of soil solution and the 35.6 c.c. of gas. The two latter are approximately equal. Reference to Table III shows that with a p.p. = 1.5, 100 volumes of gas plus 100 volumes of solution would contain $1.5 + 6.22$ volumes of CO_2 which is relatively greater than that present in the quoted case. Also it is evident that much the greater part of the CO_2 is derived from the solution. This mental estimate shows that the p.p. was < 1.5 . Equation (1) may therefore be solved with the values:

$x : y = 6.22 : 1.5$, whence $x = 4.14 y$.

and $x : y = 4.97 : 1$, whence $x = 4.97 y$.

Employing the first in eq. 2 we have:—

$$38x + 35.6y = 2.34$$

$$(38 \times 4.14)y + 35.6y = 2.34$$

$$y = 0.01215; x = 0.0502$$

$ax = 1.91$ c.c. CO_2 in solution

$by = 0.43$ „ „ „ gas

$$\text{and the p.p. } \text{CO}_2 = \frac{0.43 \times 100}{35.6} = 1.2$$

Employing the second value in equation (2) we obtain

$$y = 0.0104$$

and the p.p. $\text{CO}_2 = 1.04$

It may be pointed out here that the value of y multiplied by 100 = the p.p. CO_2 in the gas phase.

The criterion of the correctness of the calculation is the equality of the partial pressure thus found from equation (2) with that which has been employed in equation (1). Thus in this example it is evident that the second value, viz., 1.0 is much the better, and that 1.04 for the p.p. CO_2 is very near the truth. The distribution of the 2.34 c.c. CO_2 is then very nearly:—

0.37 c.c. in the gas phase

1.96 c.c. in the soil solution.

These values would not be materially different if a further approximation were made in which b is put equal to $35.6 - 1.96 = 33.64$.

The analysis of the gas had yielded the following:—

			%
N+A	..	..	83.06
O	..	..	10.18
CO_2	..	..	6.76

But after distributing the CO_2 between the gas and liquid phases, the composition of the gas phase as it existed in the soil becomes:—

			%
N+A	..	..	88.0
O	..	..	10.8
CO_2	..	..	1.2

Another example may be taken:—

Volume of siliceous material	..	..	75.8 c.c.
Do. water	..	..	52.4 „
Do. gas	..	..	29.4 „
Do. CO_2	..	..	2.93 „
$t = 30^\circ\text{C}.$			

Here not only is the volume of CO_2 small, but the liquid phase is considerably greater than the gas phase, and it is evident that most of the CO_2 is present in the liquid.

If the p.p. CO_2 is put = 1

then $x : y = 5 : 1$ (1)

and $52.4 x + 29.4 y = 2.93$ (2)

substituting

$$(52.4 \times 5) y + 29.4 y = 2.93$$

$$y = 0.0100$$

$$x = 0.0500$$

whence

$$52.4 \times 0.05 = 2.620 \text{ c.c. CO}_2 \text{ in solution}$$

$$29.4 \times 0.01 = 0.294 \text{ c.c. CO}_2 \text{ in gas}$$

$$\text{p.p. CO}_2 = \frac{0.294 \times 100}{29.4} = 1.00$$

If, however, the p.p. CO₂ be assumed = 2, then $x : y = 7.33 : 2$ and the calculation yields

$$52.4 \times 0.0485 = 2.54$$

$$29.4 \times 0.0132 = 0.39$$

$$\text{and the p.p. CO}_2 = \frac{0.39 \times 100}{2.93} = 1.32$$

instead of the p.p. 2 assumed.

Thus the first calculation is much the more correct and is in fact very near the truth.

The analysis of the gas in this example yielded :—

			%
N+A	..	..	79.0
O	..	..	10.9
CO ₂	..	..	10.1

After deducting the CO₂ which was in solution, the composition of the gas phase in the soil becomes :—

			%
N+A	..	..	86.9
O	..	..	12.0
CO ₂	..	..	1.1

The composition of the soil gases in the examples quoted in succeeding paragraphs are as found by the analysis of the gas as extracted from the soil specimens, and consequently the percentage of carbon dioxide is generally very much higher than was actually present in the gas phase in the soil. It has been considered preferable to leave the analyses thus unaltered, largely because so little is known regarding the respective functions of the dissolved and gaseous carbon dioxide. The following examples of re-calculated analyses will serve to illustrate the differences which exist between the percentage of total and gaseous carbon dioxide respectively.

TABLE IV.

Examples illustrating the percentage of total carbon dioxide and the same after correction for the part which is in solution.

	I	II	III	IV	V
Composition found by gas analysis.					
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Nitrogen plus argon ...	76.47	80.45	77.36	80.78	74.50
Oxygen ...	13.56	7.25	6.85	2.23	4.86
Carbon dioxide ...	9.97	12.30	15.79	16.99	21.14
Composition after correction for the dissolved carbon dioxide.					
Nitrogen plus argon ...	83.24	90.78	90.21	92.45	89.81
Oxygen ...	14.77	8.17	7.99	2.56	5.25
Carbon dioxide ...	1.99	1.05	1.80	5.00	1.94

Where the total carbon dioxide is much less than 10 per cent and the soil is not particularly dry it is nearly all in solution.

What proportion of CaCO_3 in the soil is necessary to satisfy any probable proportion of CO_2 as $\text{Ca}(\text{HCO}_3)_2$? In a foregoing paragraph (page 101) it has been mentioned that calculation shows that all ordinary fertile soils contain sufficient calcium carbonate to form the bicarbonate with any carbon dioxide which may occur in a soil.

The highest percentages of CO_2 which have been met with are (i) 15.79% in some green-manured soil, and (ii) 21.14% in the gases from the neighbourhood of the roots of an indigo crop.

For the present calculation the following assumptions will be made:—

- (i) CO_2 in gas = 25%
- (ii) temperature 30°C .
- (iii) 1 c. dm. of soil to include:—

	c.c.
Siliceous material ..	500
Water ..	300
Gases ..	200
including CO_2 ..	50

that is, conditions requiring an unusually high proportion of calcium carbonate

The distribution of CO_2 works out to :—

11.7 c.c. in the gas phase.

38.1 c.c. in the liquid phase.

This carbon dioxide is equivalent to 0.153 gm. CaCO_3 .

The 500 c.c. of siliceous soil material is equivalent to 1,350 gm., and 0.153 gm. of calcium carbonate is equivalent to 0.0113 per 100 dry soil. As all good arable soils contain more than this amount, and conversely an unusually high proportion of carbon dioxide has been assumed in the foregoing calculation, it may be safely concluded that all good soils contain more than sufficient calcium carbonate for the end in view.

PROPORTIONS OF OXYGEN AND CARBON DIOXIDE IN THE SOIL GASES IN FALLOW LAND.

In Table V are set out a number of examples illustrating the proportions of oxygen and carbon dioxide which have been found in the soil gases of unmanured fallow land and a number of others will be found in Table XIII (page 119). There are several points of interest.

(a) The percentage of oxygen is considerably higher in the hot dry season (April to May) than during the monsoon (June-July). The percentages naturally vary but approximately the oxygen percentage was found to fall from say 16 or 18% in the dry season to between 8 and 12% during the rains.

(b) As is evident from the quoted examples, the percentage of carbon dioxide varies within wide limits, and there seems to be as much at 5 or 6 ft. deep as in the surface soil; it increases during the monsoon but the change was marked chiefly after the first heavy rain. This point will be referred to subsequently when speaking of the changes during nitrification, but there seems to be no doubt that one of the effects of the first heavy rain is to occasion a production of this gas. The amount of carbon dioxide found in fallow land is, however, smaller than what I have met with in the neighbourhood of the roots of crops to which reference will also be made subsequently.

(c) It has been suggested by Wollny¹ that the sum of the percentages of oxygen and carbon dioxide in soil gases always approximates to 21, but this is far from being the case, and although the sum of the two often approaches this figure, there are too many exceptions to admit of this suggestion carrying any weight. The formation of carbon dioxide is doubtless dependent on the presence of oxygen, but to suggest that each volume of carbon dioxide which is formed demands one volume of oxygen would be a mistake. More exact information regarding this point is given when speaking of nitrification.

¹ *Expt. Statn. Record* IV, p. 537.

TABLE V.

Fallow land—unmanured. Proportions of oxygen and carbon dioxide.

DEPTH	1907 April 24th to May 8th.		1911 June 7th to 15th.		1911 June 27th to 29th.		1911 July 12th to 15th.		1908 Jany. 8th to 11th.	
Inches	O %	CO ₂ %	O %	CO ₂ %	O %	CO ₂ %	O %	CO ₂ %	O %	CO ₂ %
0"—3"	...	...	...	...	...	...	...	...	...	...
3"—6"	17.2	2.9	...	...	...	...	...	...	...	...
6"—9"	16.2	5.9	...	...	...	...	...	...	...	...
9"—12"	18.6	3.6	...	...	12.7	12.0	...	...	17.5	4.3
1'0"—1'3"	17.4	8.5	9.8	3.9	...	...	12.0	4.4	...	...
1'3"—1'6"	...	...	...	...	...	...	...	...	...	...
1'6"—1'9"	...	...	...	...	...	...	...	...	...	...
1'9"—2'0"	...	...	...	...	9.2	6.9	...	...	18.5	5.4
2'0"—2'3"	17.7	4.6	14.6	1.9	...	...	9.8	3.4	...	...
2'3"—2'6"	...	...	...	...	...	...	...	...	...	...
2'6"—2'9"	...	...	...	...	...	...	...	...	...	...
2'9"—3'0"	17.6	5.9	...	...	9.7	6.0	...	...	17.6	6.9
3'0"—3'3"	13.8	7.0	8.0	1.4	...	...	7.6	5.4	...	...
3'3"—3'6"	...	...	...	...	...	...	...	...	...	...
3'6"—3'9"	...	...	...	...	...	...	...	...	...	...
3'9"—4'0"	17.8	3.1	...	...	...	...	...	...	...	...
4'0"—4'3"	...	...	14.9	2.7	...	...	11.9	4.1	13.3	7.0
4'3"—4'6"	...	...	...	...	...	...	...	...	...	...
4'6"—4'9"	...	...	...	...	...	...	...	...	...	...
4'9"—5'0"	13.4	8.5	...	...	...	...	...	...	...	...
5'0"—5'3"	...	...	12.7	6.1	...	...	...	...	...	...
5'3"—5'6"	...	...	...	...	...	...	...	...	...	...
5'6"—5'9"	...	...	...	...	...	...	...	...	...	...
5'9"—6'0"	...	...	...	...	...	...	...	...	...	...
6'0"—6'3"	15.5	8.2	...	...	...	...	...	...	...	...
	After long period of dry wea. ther.		After 5.5" of rainfall in preceeding week which was absorb- ed by upper 2ft. of soil.		After 5.3" of rain in 2 weeks.		After 5.5" of rain in 2 weeks.			

PROPORTIONS OF OXYGEN AND CARBON DIOXIDE IN MANURED LAND.

A few samples of soil from land which had been manured with 20 tons of farm manure per acre were examined in 1907, and the percentage of oxygen and carbon dioxide found in the gases are set out in Table VI. The manure was applied on October 2nd and the samples were taken between October 6th and 8th and between December 21st and 24th, that is about 4 days and 11 weeks subsequently. There was some increase in the percentage of carbon dioxide, though the amount found eleven weeks after applying the manure was not very large. The number of tests was however small.

More striking is the fact that the gas of the soil some feet deep is as rich in carbon dioxide as the stratum of soil into which the manure was mixed. No doubt more carbon dioxide is formed in the latter, but being near to the surface it is enabled to pass readily into the outside atmosphere by diffusion and its concentration is thereby maintained at a low figure.

TABLE VI.

Composition of gas in fallow land after an application of 20 tons farmyard manure. Applied October 2nd, 1907.

DEPTH.		1907 October 6th to 8th.		1907 December 21st to 24th.	
Cm.	Inches	O %	CO ₂ %	O %	CO ₂ %
22·8—30·5	9"—12"	11·38	1·98	14·7	6·8
53·4—61·0	1'9"—2'0"	...	...	14·7	7·4
83·8—91·5	2'9"—3'0"	13·20	5·00	13·6	10·0
122·0—129·6	4'0"—4'3"	...	...	17·8	4·3

THE COMPOSITION OF THE GAS IN GREEN-MANURED LAND.

Tables VII and VIII contain examples of the composition of the gases found in fallow land shortly after green-manuring. Those in Table VII were obtained from single borings, each of which had a volume of 0·154 c.dm. of soil. Moreover, the weight of green manure ploughed in was not known. The samples referred to in Table VIII are the result of a more carefully controlled experiment and the gas was more completely analysed. In this case the green crop—san hemp—(*Crotalaria juncea*) was taken from an area of 4 sq. yds., cut up rapidly in a chaff cutter, then distributed as uniformly as possible over the surface of the plot from which it was cut, and

dug in. For the gas analysis, six borings aggregating 0.926 c.dm. of soil, were taken for each sample, 3, 6, and 9 days respectively after digging in the green plant, which naturally provides a more reliable index of the general composition of the soil gases as a whole than would single specimens.

TABLE VII.

Fallow land after green-manure. Proportions of oxygen and carbon dioxide.

DEPTH.		San hemp ploughed in July 14th. Analyses made July 18th to 24th.		<i>Dhaincha</i> ploughed in August 5th. Analyses made August 8th and 14th.	
Cm.	Inches	O %	CO ₂ %	O %	CO ₂ %
15.3—22.8	6"—9"	10.9	10.1	10.6	18.4
22.8—30.5	9"—12"	11.9	6.3	10.1	8.0
30.5—38.1	1' 0"—1' 3"	10.1	6.8	...	...
61.0—68.6	2' 0"—2' 3"	12.5	3.5	...	...
91.5—99.1	3' 0"—3' 3"	12.0	4.0	...	...
122.0—129.6	4' 0"—4' 3"	10.0	5.4	...	...

TABLE VIII.

Composition of gas from green-manured land. Dug in September 11th, 1914.

Date				14-9-14.	17-9-14.	20-9-14.
Depth cm.				7.6—15.3	7.6—15.3	7.6—15.3
,, inches				3"—6"	3"—6"	3"—6"
Volume of gas per c.dm. of soil.				c.c. 214.7	c.c. 107.1	c.c. 159.5
Nitrogen				Per cent. 78.42	Per cent. 82.70	Per cent. 76.43
Oxygen				7.48	8.81	6.85
Carbon dioxide				13.06	7.25	15.79
Hydrogen				Nll	.21	Nll
Methane				Nll	Nll	Nll
Argon				1.043	1.032	0.935
$\frac{N}{A}$				75	80	81.5
$\frac{O}{A}$				7.1	8.5	7.2
Rainfall notes				0.15" rain on previous evening.	0.03" on 14th and 1.31" rain on even- ing of 16th.	No further rainfall.

It will be seen that the volume of gas obtained on the three dates varies considerably, a variation which is associated with the rainfall. Before September 14th there had been practically dry weather for 10 days. On the evening of 16th September 1.31 in. of rain fell and its effect by the following morning was to reduce the amount of gas from 214 c.c. to 107 c.c. per c.dm. in the surface soil temporarily. No more rain fell before 20th September with the natural result that a considerable increase of gas was found on the latter date. It would be unreasonable to conclude from a single experiment that the rainfall of the 16th caused a decrease in the amount of carbon dioxide such as the figures indicate. It is, however, evident from the presence of hydrogen gas after the somewhat heavy rain of 16th that other changes set in temporarily.

Regarding the nitrogen, it has been thought probable that this element is frequently set free from its combined state in manures by bacterial agency. The subject is referred to for instance by Russell¹ who deduces a considerable annual loss from land at Rothamsted on which large amounts of farm manure had been annually applied for 40 years.

An estimate of the amount of organic nitrogen which the green manure contained was made from the weight and analysis of the plant growing on the next neighbouring ground, and which came to 0.0886 gm. N per sq. dm. of surface. The object in view had been to compare this with any excess of nitrogen which the analysis of the soil gases might indicate, and hence form an estimate of what proportion (if any) of the nitrogen in the green manure had been set free in the elementary state. It is true that the analyses actually show an increase of nitrogen during the period, the N : A ratios being 75, 80, 81.5 respectively. But these differences lie within the experimental error (see page 95), and the apparent increase must be referred to this cause.

As a matter of fact the nitrogen in green manure is small compared with the nitrogen gas commonly present in the soil. Thus, in the experiment under reference, the weight of green plant was about 8 tons per acre. The total nitrogen in it was equal to 0.0886 gram per 1 sq. dm. of surface. Assuming that the material is uniformly distributed throughout the upper 1.5 dm. (6 inches) of soil, the comparison may be made between the volume of nitrogen gas present in the soil and the nitrogen (combined) of the green manure. The former was (on September 14th and assuming that the first 3 inches of soil contained the same amount of gas as the second 3 inches) 255 c.c. whilst the latter is equal to 71 c.c. N per 1.5 c. dm. of soil. Thus

¹ E. J. Russell. *Soil conditions and plant growth*, p. 82.

supposing one-tenth part of the nitrogen of the green manure were liberated as gas, it would not alter the $\frac{N}{A}$ ratio sufficiently to admit of its detection, unless the experimental error were reduced considerably below what I have commonly found.

An experiment was made in a closed vessel of known volume, in which 100 grm. air-dry soil + 1.0 grm. green leaf of *Poinciana regia* (gulmohr) + about 19 grm. water were allowed to stand for 15 days at room temperature (about 30°C); the gas was then pumped out and analysed. The following are the data:—

100 grm. air-dry soil (D=2.71)	..	..	36.9	c.c.
19.2 grm. water	..	..	19.2	„
1 grm. leaf	..	..	1.0	„
Damp air at 29°C	..	..	1656.3	„

Volume of flask	1713.4
-----------------	----	----	----	--------

1656.3 c.c. damp air at 29°C equals 1429.1 c.c. dry air N.T.P.

			Initial		Final
N+A	..	..	1129.6	c.c.	1134.1 c.c.
O	..	..	299.1	„	187.68 „
CO ₂	..	..	0.43	„	96.23 „
			1429.1		1418.01

The difference between the volumes of N+A initially present and found when the gases were pumped out is 4.5 c.c. This may be due to one or both of two causes, (i) inaccuracy in the estimate of the original volume of air, and (ii) the evolution of N. gas from the organic matter. As to the first it is derived from the difference:—

Volume of flask—(volume of soil+volume of green leaf+volume of water) each of which is known with considerable accuracy. But it had to be assumed that the air in the flask was fully saturated with moisture when the flask was closed. If the relative humidity had been 90 % instead of 100 % as assumed, then the volume of N+A in the enclosed air would have been 1134.0 c.c. It is not likely that the humidity was actually so low as 90 %, but it is well known that to fully saturate a gas in a flask of 1.5 litre capacity without agitation requires some little time, and consequently that a part, at least, of the difference between the estimated initial N+A and that measured at the conclusion of the experiment was due to this source of error.

It is therefore to be concluded that either no nitrogen was liberated in the elementary state, or that its volume was small.

THE GASES OF SWAMP RICE LAND.

The conditions under which "wet" paddy grows is a theme which Harrison and Subramania Aiyer have dealt with at some length¹ and the investigation is still in progress. In the first of these contributions it was pointed out that the nitrogen in the evolved gases must be derived from one or all of three sources ; (a) the gases present in the soil at the time when the land is submerged for paddy cultivation and which therefore is in part imprisoned, (b) the atmospheric nitrogen which is dissolved in the irrigation water, (c) the organic nitrogenous substance of the soil and green manure. Measurements of the amount of nitrogen evolved from plots showed that this was very considerably greater from manured than from un-manured land, and this result was substantiated by pot-cultures. The inference was therefore made that a part at least of the gaseous nitrogen was derived from the green manure. Direct evidence was nevertheless very desirable and Mr. Harrison sent me samples of these gases in 1914 in order to determine the N : A ratio. The analyses are set out in Table IX.

TABLE IX.
Composition of gas from swamp rice land.

	A.	B.	C.
Nitrogen	84.25	86.60	85.91
Oxygen	0.32	0.31	0.99
Carbon dioxide	4.34	4.23	4.69
Hydrogen	8.81	3.91	4.53
Methane	1.37	4.06	3.00
Argon	0.915	0.885	0.879
$\frac{N}{A}$	92	98	97

A glance at the N : A ratios shows that these are so high that there is no doubt at all that nitrogen has been liberated. Under the conditions of the cultivation of this crop atmospheric air is very largely excluded, and the argon present is necessarily largely obtained from the gases dissolved in the irrigation water. The ratio N : A dissolved in water when freely exposed to the air is 33.8 at 30°C, and if no nitrogen were obtained from other sources, these two elements would be present in the paddy land gases in a proportion not widely different from this. If, for example, one volume of water saturated with air were shaken with an equal volume of gas containing neither nitrogen nor argon, the N/A ratio in the gas phase would become 33.5 ; if the one volume of water were shaken with one-tenth its

¹ Mem., Dept. Agri. Ind., Chem. Series, Vol. III, No. 3, & Vol. IV, No. 1.

volume of other gas, the N/A ratio would be 39 (assumed temperature = 30°C.) There can therefore be no doubt that a high proportion of the nitrogen found in these gases is derived from the soil and manure.

THE GASES PRESENT IN THE NEIGHBOURHOOD OF THE ROOTS OF CROPS.

A number of samples of gas from the neighbourhood of crop-roots have been examined. It may be mentioned that the original object in view was to try to ascertain whether the assimilation of elementary nitrogen by a papilionaceous crop could be detected by the aid of the N : A ratio, although it had to be realized at the outset that the amount of nitrogen thus disappearing from the soil gases was probably too small to admit of its detection. Apart from this, the examination of these gases is of considerable interest in other respects, for the amounts of oxygen are unexpectedly small, those of carbon dioxide very large, and the presence of hydrogen had not been suspected.

Referring to the amount of nitrogen assimilated by a papilionaceous crop, the following is an estimate showing the relation between the combined nitrogen in the crop and the gaseous nitrogen in the soil respectively. Employing san hemp as an example, the amount of nitrogen found in several samples in July 1914 varied from 50 to 70 lb. per acre. Assuming 60 lb. as an average quantity, this is equivalent to 0.0672 gram per sq. dm. of soil surface. It is by no means the case that all the nitrogen of these crops is usually assimilated from the elementary state,¹ and it is moreover still quite uncertain whether the assimilation takes place through the roots or through the above-ground parts of the plant, though most authorities favour the former view. But assuming merely for the purposes of the present calculation that the whole of the nitrogen of the crop is assimilated through the root system and that it is obtained entirely from the gaseous nitrogen of the upper two feet of soil, the comparison becomes between the quantity 0.0672 gram nitrogen in the crop and the elementary nitrogen which is in say the upper two feet or 6.1 decimetre of soil. The data contained in Table X indicate that 1 c.dm. of the Pusa soil usually includes during the monsoon say 0.150 to 0.200 c. dm. of gas containing say 80% nitrogen. The temperature may be assumed to be about 30°C. Thus in the upper two feet, or 6.1 decimetre of soil there may be expected to be at least some 0.732 c. dm. nitrogen in 6.1 c. dm. of soil. This quantity of nitrogen would weigh 0.821 grm. We have then the relation 0.821 : 0.0672 and it becomes apparent that even on the excessive assumption employed, the amount of nitrogen assimilated would

¹ Lawes & Gilbert, *J. R. A. S. E.*, 3rd Series, Vol. II, p. 696.

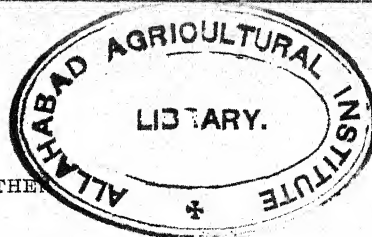


TABLE X.
Composition of gas from the soil near the roots of crops.

Date	San hemp (<i>Crotalaria juncea</i>)				Indigo (<i>Indigofera arrecta</i>)				Maize (<i>Zea mays</i>)			
	27.7.14	30.7.14	3.8.14	25.8.14	18.8.14	20.8.14	23.8.14	4.9.14	6.9.14	8.9.14	10.9.14	
Depth cm. ...	7.6-5.2	15.2-22.8	30.5-38.1	7.6-15.2	7.6-15.2	15.2-22.8	30.5-38.1	7.6-15.2	15.2-22.8	30.5-38.1	7.6-15.2	
" inches ...	3"-6"	6"-9"	12"-15"	3"-6"	3"-6"	6"-9"	12"-15"	3"-6"	6"-9"	12"-15"	3"-6"	
Volume of gas per 1 c. dm. soil ...	c.c. 250.0	c.c. 195.4	c.c. 149.3	c.c. 224.1	c.c. 134.9	c.c. 212.0	c.c. 177.4	c.c. 54.93	c.c. 146.5	c.c. 193.9	c.c. 158.9	
Nitrogen ...	% 79.77	% 83.73	% 85.05	% 81.63	% 79.39	% 72.96	% 82.26	% 81.59	% 82.59	% 76.94	% 79.47	
Oxygen ...	2.23	5.81	9.00	4.67	5.24	4.36	3.33	13.82	6.28	8.65	7.25	
Carbon dioxide ...	16.99	9.36	4.84	12.12	13.80	21.14	12.62	3.34	8.71	12.08	12.80	
Hydrogen ...	.....	.....	.....	0.582	.....	0.637	0.743	0.18	1.39	1.37	Nil.	
Methane ...	.....	.....	.....	Nil.	.....	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	
Argon ...	1.010	1.101	1.111	0.999	0.967	0.906	1.041	1.073	1.028	0.956	0.981	
N ...	79	76	76	82	83	80	79	76	80	81	81	
A ...	2.2	5.3	8.1	4.7	5.4	4.8	3.2	12.9	6.1	9.6	7.4	
O ...												
A ...												
Rainfall notes	Last heavy rain July 15th.	No more rain.	4.17" in 4 days.		Last heavy rain Aug. 14th.	No more rain.	No more rain.	15.27" in preceding 9 days.	No more rain.	No more rain.	0.11" more rain.	

be only small in comparison to the whole gas present. When further it is recollected that the nitrogen of the crop is assimilated in part as combined nitrogen, that the portion assimilated is taken up gradually during several months, that any reduction in the nitrogen partial-pressure would be constantly rectified by the agency of diffusion from the atmosphere, it becomes certain that the actual effect of nitrogen assimilation by these crops on the N: A ratio will be so small as to demand for its detection a much higher degree of accuracy than I have been able to attain with small volumes of gas, if indeed it could be detected in this manner at all.

After finding the frequently low proportions of oxygen and high proportions of carbon dioxide, in the earlier samples, it was thought possible that hydrogen or methane might be present, and the result of the examination for these gases showed that although no methane or other hydrocarbon was met with, hydrogen is a common constituent. The quantities are small, but are nevertheless quite definite. This gas was found in the neighbourhood of the roots of all the three crops, san hemp, indigo and maize. The composition of these gases possesses perhaps the most interest of any. We are unfortunately very ignorant at the present day of the nature of the lower organisms which accompany the development of higher plants, but the idea of certain specific associations between higher plants and soil organisms naturally presents itself as probable. It may be assumed as highly improbable that hydrogen is liberated by the higher plant, and indeed it is doubtful whether such experimental evidence as exists is sufficient to prove that carbon dioxide is thus produced. So far as I am aware, the proof of the production of carbon dioxide by the roots of crops rests on experiments made in the presence of other lower forms of plant-life and which latter are known to be a source of carbon dioxide.

NITRIFICATION.

In a memoir of this series dealing with some records of drainage, three circumstances among others in respect of soil nitrates were referred to, namely: (i) the difference between the amounts of nitrate, obtained from the drain-gauges of cropped and fallow soil respectively, was much greater than could be accounted for by simple crop assimilation¹; (ii) energetic nitrification occurred in fallow soil immediately after the first heavy rain of the monsoon²; (iii) the amount of nitrate then formed is so great, that the

¹ *Mem., Dept. Agri. Ind., Chem. Series*, Vol. II, No. 2, p. 94.

² *Ibid.*, p. 101.

equivalent amount of oxygen is nearly equal to and in some cases has exceeded that which would be present in the soil in the gaseous state,¹ or alternatively as oxygen and carbon dioxide, since the latter gas is closely associated with nitrification.

Principally in order to try to gain a knowledge of the proportions of oxygen and carbon dioxide gases which are present during a period of intensive nitrification, some special tests were made in June 1914, which will be referred to presently. Incidentally, however, some further information was gained regarding the other two points and this may be suitably referred to here.

Nitrification is especially active in fallow soil immediately after the first heavy monsoon rainfall.—This has proved to be uniformly the case, as the figures in the subjoined table show:—

TABLE XI.

Pounds (avoir.) of nitric-nitrogen per acre $\times \frac{1}{2}$ foot, in fallow land.

DEPTH		1910		1911		1914	
Cm.	Inches	25th May	18th June	4th May	10th June	30th May	24th June
0—15·2	0"—6"	lb. 1·20	lb. 3·30	lb. 4·37	lb. 1·97	lb. 9·48	lb. 3·44
15·2—30·5	6"—12"	0·66	18·31	1·58	18·95	0·71	22·20

Rainfall 1910 : principally 0·78" on June 1st.

2·15" on June 15th.

0·29" on June 16th.

0·94" on June 17th.

Do. 1911 : principally 0·25" on June 5th.

0·80" on June 6th.

2·31" on June 8th.

Do. 1914 : principally 1·32" on June 9th.

1·71" on June 17th.

Effect of a crop on nitrification.—The evidence on this subject which was offered in the memoir on drainage consisted in a comparison between the

¹ *Mem., Dept. Agri. Ind., Chem. Series, Vol. II, No. 2, p. 116.*

amounts of nitric-nitrogen found in the drainage waters from fallow-soil and cropped-soil respectively. Some further evidence was met with in 1914. Wheat had been cultivated during the cold-weather of 1913-14 on one half of a plot of land (the whole of which had been "green-manured" with san hemp in 1913) and had been harvested early in April, after which this portion of the land was also well cultivated with the hoe; that is to say, one half the plot had been green-manured and then left fallow for nine months, whilst the other half had been green-manured, had borne a crop of wheat, and had then been fallow for two months. Determinations of the nitrate in the soil were made before and after the first heavy monsoon rain, when it was found that where the wheat crop had grown, hardly any nitrification had occurred, as the following Table XII shows:—

TABLE XII.

Pounds (avoir.) of nitric-nitrogen per acre $\times \frac{1}{2}$ foot, after fallow and wheat respectively.

DEPTH		AFTER FALLOW			AFTER WHEAT		
Cm.	Inches	30th May	Rainfall inches	24th June	30th May	Rainfall inches	24th June
0—15.2	0"—6"	lb. 9.48	4.21	lb. 3.44	lb. 1.32	4.21	lb. 4.91
15.2—30.5	6"—12"	0.71		22.20	0.42		1.97

In the Memoir on Drainage (p. 97) the conclusion was drawn that the deficiency of nitrate in the drainage water after crops (wheat and maize) was, of three possible causes, most probably due to an effect of the higher plant on soil organisms. The experiment of 1914 now quoted also supports this view. It is true it might properly be suggested that the wheat crop had drawn on the store of readily nitrifiable matter in the soil to such an extent as to leave but little for immediate nitrification; but against this being the probably correct explanation is the fact that the Pusa soil yields comparatively large amounts of nitrate annually when fallow and without the aid of any manurial substance, *i.e.*, the amount of nitrate formed in the Pusa soil is large when no manure has been used. For example, the amount of nitrate formed in June 1914 after green-manuring is not very different from the amounts formed in 1910 and 1911 after the simple fallow (*See Table XI*).

The composition of the soil-gases during nitrification.—In 1914 the gases contained in the soil, "after fallow," referred to in Table XII, both before and after the first heavy rain of the monsoon, were extracted, measured and analysed. It was anticipated that an abundant nitrification would occur, which anticipation was realized. The amount of nitrate quoted is the mean of four samples in each case. For the gas analyses four specimens of the first three inches of soil were examined at the end of May, and two specimens were examined for each of the other depths. The mean of these analyses are quoted in the subjoined Table XIII :—

TABLE XIII.

The composition of the gas in fallow land before and after nitrification.

Date	DEPTH		Nitrogen %	Oxygen %	Carbon dioxide %	Argon %	RATIO	
	Cm.	Inches					$\frac{O}{A}$	$\frac{N}{A}$
May 30th ...	0—7·6	0"—3"	78·45	20·44	0·12	0·988	20·6	79
June 1st ...	7·6—15·2	3"—6"	78·44	20·30	0·25	1·007	20·2	78
June 2nd ...	15·2—22·8	6"—9"	77·08	20·29	1·65	0·976	20·8	79
June 3rd ...	22·8—30·5	9"—12"	78·21	20·56	0·29	0·937	22·0	84

Rainfall—4·21".

June 19th and 20th	0—7·6	0"—3"	78·43	19·64	0·97	0·954	20·5	82
	7·6—15·2	3"—6"	78·85	19·67	0·56	0·923	21·4	85
	15·2—22·8	6"—9"	79·10	18·99	0·94	0·967	19·7	82
	22·8—30·5	9"—12"	78·95	18·75	1·32	0·978	19·2	81

NOTE.—Rainfall included principally :—1·32" on June 9th, 0·75" on June 11th, and 1·71" on June 17th.

These figures were not what I had anticipated. The amount of nitrate which had formed so quickly demanded a considerable consumption of oxygen—directly or indirectly—whilst actually the effect on the proportion of this constituent is only nominal. Any reduction in the proportion of oxygen would naturally set up diffusion of this gas from the atmosphere, but this process has been usually looked upon as only a very slow one. It was evident at least that measurements in the field did not add much to our knowledge of the quantities of either oxygen or of carbon dioxide which are involved under the circumstances.

Recourse was then had to measurements of the gases in contact with soils contained in closed vessels. Two series of such measurements were made, (i) in vessels not much larger than sufficient to contain the soil, and (ii) in much larger vessels. The volume of air included in the former was somewhat (about one-third) greater than would be present in the natural soil; whilst in the latter series it was about seven times as great. In each case the slightly damped soil was packed carefully into the vessel so as to occupy approximately the volume it would do in the field, and a dilute solution (0.157 gram $(\text{NH}_4)_2\text{SO}_4$ per 100 c.c.) of ammonium sulphate was then gradually added drop by drop; this solution rapidly distributed itself throughout the soil. The vessel was closed with a paraffined cork and had also a tapped exit tube. These vessels were quite gastight under the conditions of the experiment. They were then incubated at 30°C . for about three weeks. Other portions of the same soils tested weekly in order to ascertain the rate of nitrification indicated three weeks as a suitable period to allow. When pumping the gases out of the vessels, the cork stoppers were submerged in water.

Respecting the estimation of the initial volume of air which was enclosed, this was derived from (i) the known volume of the vessel and its exit tube, (ii) the volume of the soil derived from its weight and specific gravity, (iii) the known volume of water added, (iv) the temperature of the air. The data are collected in the two following Tables XIV and XV. An examination of these two sets of data shows very clearly what occurred under the two different conditions. Where the total volume of air was only slightly more than what is actually present in the soil, substantially all the oxygen disappeared and a large amount of carbon dioxide was produced. The two volumes of these gases are by no means identical; in No. I that of carbon dioxide is considerably less than the oxygen which disappeared, in No. II they are approximately equal, in No. III the carbon dioxide is much in excess of the oxygen. At the same time all, or practically all, the nitrate which the soil originally contained disappeared. In the second series, where the volume of air was very much greater, there was again an almost complete utilization of oxygen, accompanied by the formation of a large quantity of carbon dioxide, the volume of the latter being however very much smaller than the oxygen which disappeared. At the same time a considerable amount of nitrate formed, this being in two cases more than 40 parts nitrogen per million parts of soil, which is higher than is commonly found in the field even under good conditions. The total volume of oxygen in the carbon dioxide and the nitrate is considerably less than that of oxygen which disappeared.

TABLE XIV.

*The changes in the quantities of gases in contact with damp soil
(small vessels).*

	I		II		III	
Date of commencement ...	28-1-15		29-1-15		3-2-15	
Do. termination ...	22-2-15		17-2-15		22-2-15	
Soil, grm. ...	79		80		100	
Water ,, ...	12		11.6		14.1	
Air moist ...	45.2 c.c.		40.4 c.c.		56.95 c.c.	
Air, N. T. P. dry ...	40.95 c.c.		36.6 c.c.		51.59 c.c.	
	Initial %	Final %	Initial %	Final %	Initial %	Final %
N + A ...	79.07	85.67		80.73		73.92
O ...	20.93	0.35		0.13		2.00
CO ₂ ...	...	13.98		19.14		24.08
	100.00	100.00		100.00		100.00
	Volumes		Volumes		Volumes	
	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
N + A ..	32.38	34.26	28.94	31.37	40.79	44.82
O ..	8.57	0.14	7.36	0.05	10.80	1.21
CO ₂ ...	...	5.59	...	7.44	...	14.60
	40.95	39.99	36.60	38.86	51.59	60.63
	m. grm.	m. grm.	m. grm.	m. grm.	m. grm.	m. grm.
Nitric-nitrogen ..	0.96	nil	0.96	nil	0.26	0.045

TABLE XV.

The changes in the quantities of gases in contact with damp soil (large vessels).

		I		II		III		IV	
Commenced	...	4-3-15		8-3-15		10-3-15		14-5-15	
Terminated	...	30-3-15		30-3-15		31-3-15		2-6-15	
Soil, grm.	...	100		100		100		100	
Water, grm.	...	15.2		14.1		14.5		13.8	
Air	...	257.6 c.c.		255.0 c.c.		241.3 c.c.		328.8 c.c.	
Equivalent to c.c. at N. T. P.	...	229.9 c.c.		223.94 c.c.		214.19 c.c.		277.3 c.c.	
		Initial %	Final %	Initial %	Final %	Initial %	Final %	Initial %	Final %
N + A	...	79.07	87.00		86.68		85.87		85.37
O	...	20.93	0.41		0.06		0.05		2.50
CO ₂	...	...	12.59		13.26		14.08		12.13
		100.00	100.00		100.00		100.00		100.00
		Volumes		Volumes		Volumes		Volumes	
		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
N + A	...	181.8	181.14	177.00	181.09	169.30	167.79	219.20	222.65
O	...	48.1	0.85	46.87	0.12	44.83	0.10	58.04	6.52
CO ₂	...	...	26.21	0.07	27.70	0.06	27.51	0.08	31.63
		229.9	208.20	223.94	208.91	214.19	195.40	277.32	260.80
		m. grm.	m. grm.	m. grm.	m. grm.	m. grm.	m. grm.	m. grm.	m. grm.
Nitric Nitrogen initial	...	1.24	2.79	0.19	4.86	0.67	4.77	0.17	4.05
Freshly formed	...		1.55		4.67		4.10		3.88
Equal to O	...		5.3		16.0		14.1		13.3
Equivalent Vol.	...		3.7 c.c.		11.2 c.c.		9.8 c.c.		9.3 c.c.

Regarding the nitrogen, denitrification and liberation of nitrogen gas may have occurred in the first series, but the figures cannot properly be employed as a proof of this because the volumes of nitrogen gas, equivalent to the nitrate which disappeared, (namely 0.77, 0.77, 0.17 c.c. respectively) are considerably smaller than the increased volumes of nitrogen *plus* argon. There is necessarily some error in computing the initial volume of air in the vessel, and to this must in part be referred the apparent increase of nitrogen gas.

These measurements of the oxygen and carbon dioxide not only illustrate the large amounts of these two gases which are involved, but also, when considered in conjunction with the composition of soil gases during a period of active nitrification in the field, (Table XIII) demonstrate the fact that diffusion of gases through soils is at least so rapid that the proportion of oxygen is maintained nearly equal to that in the atmosphere, whilst conversely that of carbon dioxide is maintained quite low. Regarding the very small proportion of oxygen which was finally present in the second series of laboratory experiments, it would naturally be a mistake to conclude that the nitrate was formed principally subsequent to the formation of the carbon dioxide; it may have formed whilst there was still much oxygen present. At the same time, whilst it is well established that the presence of oxygen gas is necessary to the process of nitrification, exaggerated ideas frequently prevail on this matter. Schloesing and Münz found that nitrification occurred when the superincumbent gas contained only 1.5 per cent. Moreover it is well established that the presence of free carbon dioxide, as well as a suitable base, is as essential as oxygen to this process.¹

DIFFUSION OF GASES THROUGH SOILS.

The foregoing paragraphs provide information in respect of the composition of the gaseous mixture present in the soil at the particular time when the samples were taken, but do not indicate the amount of gaseous interchange which must be constantly in progress through the agency of diffusion between the soil and the atmosphere. For it will be readily appreciated that, for example, where the soil gas contains a higher percentage of carbon dioxide than is present in the air, this gas will tend to pass outwards; or if oxygen gas is being consumed in the soil, its proportion in the soil gas will be reduced below that in the atmosphere, and more oxygen will pass into the soil. Again, the result of these two processes may be to alter

¹ Lafar. *Handb. d. technische Mykologie*, pp. 163, 173.

the percentage of nitrogen; the decrease of oxygen may exceed the increase of gaseous carbon dioxide, and in such a case nitrogen would diffuse outwards. The same would apply to the argon.

It is usual to attribute the value of ploughing or harrowing the surface soil largely to the exposure of this soil stratum to the air; and when a green manure is dug or ploughed into the surface soil, the latter is left as loose as possible for the ready admission of atmospheric oxygen and the equally free escape of the carbon dioxide produced. Such a mental picture of the case is naturally readily assimilated, and questions regarding the soil 6 or 8 inches below the surface, and which is commonly never disturbed, do not necessarily trouble the agriculturist. As a matter of fact he knows that good cultivation of the surface soil is productive of good crops, and if he is told that the chief explanation for the advantage lies in the necessity for allowing atmospheric oxygen to enter or carbon dioxide to leave the soil, he naturally accepts it; the acceptance costs nothing and does not in any way affect his appreciation of good cultivation, which is based on outturn of crops. But the tests made in relation to nitrification brought the question of diffusion of soil gases very particularly into prominence, because these demonstrated that the process was at least so rapid that large amounts of oxygen from the atmosphere must have passed not only into the cultivated upper soil but also into the undisturbed soil below, and that the carbon dioxide produced escaped with equal facility.

Direct experimental evidence as to the rate of diffusion of gases through soils is apparently limited to that provided by E. Buckingham¹ who concluded that the quantity of gas diffusing depended *inter alia* on the soil "interspace" or "pore-space" occupied by gases, that is, in fact on that fraction of the total soil volume which is not occupied by either soil material or water; and he deduced the formula:—

$$D = K S^2 \Delta \dots\dots\dots (i).$$

in which D = the mass of gas diffusing in unit time through unit cross-section of soil.

K = the coefficient of diffusion for the particular gas.

S = the porosity of the soil.

Δ = the difference of partial pressure of the gas on the two surfaces. (See ii below).

¹ E. Buckingham. Contribution to our knowledge of the aeration of soils. *U. S. Dept. Agric. Bureau of Soils, Bull.* 25 (1904).

Thus the free diffusion which would occur between the gases if no soil were present, is controlled or reduced by the soil material and water. The whole volume of the soil is expressed as unity, and Buckingham gives the name "porosity" to that fraction of the whole volume of soil which is occupied by gas, a term which will be here adhered to.

The determination of the rate of diffusion of gases through soils is accompanied by more than usual difficulties and there is admittedly a want of good agreement among Buckingham's experimental data. Moreover the soils employed were filled into the apparatus and artificially packed; soils in their natural state would have been preferable. But after giving every weight to these points, one must conclude that Buckingham's experimental data are not so far removed from the truth as to be useless. The values which he obtained for the index (Equation 1) were in some cases approximately 1, in others nearly as high as 3, but the majority of the values approach 2 so closely that it may safely be employed for approximations regarding diffusion through soils. More than approximations are not possible for other reasons which will be subsequently referred to. Again as touching Buckingham's experimental data, although the soils were artificially packed, the degree of packing as represented by the porosity was quite similar to that which exists in nature. It is necessary when considering the reliability of these experimental data, to bear in mind that independent evidence of the reliability of the calculated quantity of a gas diffusing into or out of the soil is very difficult to obtain, and yet in the absence of such evidence, the result of any calculations of the quantities would only carry weight if the premises of the calculation were incontestably sound.

Buckingham's formula has been applied to certain of the previously quoted examples of soil gases, and the calculated quantities of gases diffusing per day can, in some of them, be compared with extraneous evidence. The quantities of gas so obtained have been transposed to *volumes* since these will be more readily appreciated than if they were expressed in terms of mass.

Before considering the data, it is desirable to refer to the various factors which in addition to the soil and its physical state control gaseous diffusion; these are as follows:—

(i) The mass of gas diffusing naturally varies with both the cross-section and the length or thickness of the soil column as well as with the time period; these can be perfectly defined, and the units here adopted are c. dm. of gas per 1 dm. per 1 sq. dm. per day.

(ii) The mass of a gas diffusing depends on the difference between the pressure exerted by this gas on the one and the other end of the soil-column respectively. This pressure is called the partial pressure of this particular gas, when the total pressure of the gaseous mixture is equal on both sides of the soil-column. The total pressure in the case of soil gases may be assumed to be that of the atmosphere within very small limits. If the gaseous mixture contains say 1% of a certain gas, that gas is exerting $\frac{1}{100}$ part of the total pressure, and its partial pressure may be defined either as 1% or 0.01, or 0.76 cm. of mercury, according as the total pressure is defined as 100, or 1, or 76 cm. of mercury. For our purposes the total pressure is defined as 100. Thus if the soil gas at 1 dm. depth contained 1.03% CO_2 and the atmosphere contained 0.03%, the difference (Δ) would be 1, and the quantity of carbon dioxide passing out of the soil would be the $\frac{1}{100}$ part as much as would pass out if the gas in the soil were pure (*i.e.*, 100%) CO_2 and if the air contained none. This partial pressure difference is sometimes referred to as the gradient. Other things being equal, the quantity of a gas diffusing depends directly on this gradient. The unit adopted here is a gradient of 1% per 1 dm.

(iii) The quantity of gas diffusing depends finally on the temperature; it is facilitated by a rise of temperature, and other conditions being fixed, the quantity varies as $(1 + \alpha t)^2$. For present calculations a temperature of 30°C. has been adopted as being approximately representative of the conditions subsisting when the samples were taken.

(iv) The co-efficients of diffusion used are multiples of those determined by Obermayer¹ for the diffusion of O, CO_2 , and H into air, and N into O respectively in order to agree with units here adopted.

But whilst the foregoing conditions are perfectly defined, those occurring in the soil must be regarded as changing so rapidly that it is quite impossible to define the latter very precisely. For example, consider the temperature. This will vary at 1" from the surface in June from say 24° to 40°C. during the 24 hours. The variations in the deeper soil are less, until at 24" deep the diurnal variation is negligibly small². The effect of a temperature difference such as that near the surface would be to alter the rate of diffusion by about 12%, but since the temperature change decreases with the depth it cannot be defined for any particular soil stratum. By employing the mean temperature = 30°C., the error due to temperature variation is reduced to much smaller dimensions

¹ Winkelmann. *Handb. d. Physik*, Vol. I, pp. 14—21.

² J. W. Leather. *Soil Temperatures, Mem. Dept. Agric. Ind. Chem. Series*, Vol. IV, No. 2, p. 36.

than are other probable errors. Again the absorption of oxygen, or the production of carbon dioxide being due to bio-chemical processes must be regarded as suffering constant change. The instances which will be here considered occurred generally between 3" and 15" deep in the soil, *i.e.*, where the diurnal temperature changes were comparatively small, but moisture conditions were in some cases suffering rapid changes, and these may have affected the rate of absorption or production respectively. Finally changes in water-content also occasion changes in the porosity. The nett result of such varying conditions is to show that, although the examination of the soil gases yields certain defined values for the partial pressure differences, these are in actuality constantly changing from hour to hour or from day to day in no small degree. A series of diffusion waves are thus set up in both directions which it would be impossible to define accurately. This is well illustrated by the examples to be quoted. Nevertheless for purposes of calculation it has been assumed that a certain gradient existed for a sufficiently long time to allow of the use of the foregoing equation.

The values of K are as follows :—

$$\begin{array}{lcl} K_N & = & 1.903 \\ K_O & = & 1.892 \\ K_{CO_2} & = & 1.435 \\ K_H & = & 6.805 \end{array} \left\{ \begin{array}{l} \text{mass per sq. dm. per day through 1 dm.} \\ \text{when p.p. } \Delta = 1\% \text{ and } t = 30^\circ\text{C.} \end{array} \right.$$

A special remark applies to the carbon dioxide. It has been explained that a part of this compound is present as calcium bicarbonate, and a part in the simple gaseous state. It is only the latter which is subject to the laws of diffusion.

Turning now to examples, that relating to the conditions of nitrification (Table XIII) may be first considered. In this case oxygen was passing into the soil in part to produce carbon dioxide and nitrate and in part for other reasons which we know practically nothing of. These facts are well known,¹ but the amount of oxygen (in excess of the CO₂ and nitrate requirement) consumed by the Pusa soil in my experiments (Table XII) is very much greater than Dehérain and Demousy found (Russell unfortunately did not measure the volumes) and the supply of oxygen was not even then sufficient. During the period of nitrification in the field (June 1914), carbon dioxide was produced, some of which would pass into the form of calcium bicarbonate in solution, whilst another portion would diffuse outwards into the atmosphere.

¹ Dehérain et Demousy, *Ann. Agron.*, XXII (1906), p. 305. E. J. Russell, *J. Agri. Sci.*, I (1905), 261.

At the same time a larger volume of oxygen would tend to diffuse into the soil to meet the demand there created. There would, on account of these changes, be a tendency for the percentage of nitrogen to increase in the soil gas, so that its partial pressure would rise above that in the atmosphere, and thus cause nitrogen to diffuse outwards. The same would apply to the argon, but the quantities of this element taking part in the gaseous interchanges are too small to affect our principal conclusions and have been neglected from the calculated quantities. The analyses quoted in Table XIII show also that the above description of the processes is correct; the proportions of nitrogen and carbon dioxide have risen whilst those of oxygen have fallen in all parts of the soil. The calculation shows that:—

0.429 c. dm. of nitrogen

0.017 c. dm. of carbon dioxide

were diffusing out of the soil, whilst,

0.454 c. dm. of oxygen was diffusing into the soil per day, when the samples were taken.

The question then follows, how do these quantities compare with those involved in the laboratory experiments made in closed vessels? Assuming that the production of carbon dioxide commenced principally after the heavy rain of June 9th, and remained substantially constant, 0.17 c. dm. or 170 c. c. CO_2 per sq. dm. passed out of the surface soil during the 10 days, and since we know that the nitrate was formed in the second 6" of soil, and that a good deal of CO_2 was formed in this stratum, the total amount must be distributed throughout this depth. The depth is equivalent to approximately 3 dm., and the weight of dry soil in 3 c. dm. is about 4,000 grams. Thus the quantity of carbon dioxide formed in 10 days in the soil is equivalent to $\frac{170}{40} = 4.2$ c.c. per 100 gm. soil. It is also necessary to refer to the carbon dioxide which was present as calcium bicarbonate. Although its amount, at any one time, exceeds that which is in the gaseous state, this solution is comparatively stationary in the soil, and calculation shows that its quantity is so much less than that estimated to have diffused out of the soil during 10 days that it may be neglected from the estimate. In the experiment with 100 grams of soil enclosed in the bottle, 31 c.c. (approximately) were formed during 22 days. If more oxygen had been present more carbon dioxide *might* have been formed, and conversely the carbon dioxide which was formed may have been largely formed in the earlier part of the period. However the comparison is made, the quantity of this gas which is calculated to have diffused from the soil seems to be distinctly smaller than the laboratory experiment would indicate. On the other hand considering that the soils were not

identical—though of the same class—that more carbon dioxide may have been diffusing from the field in the earlier days, *i.e.*, before the samples were taken and the conditions in other respects very different, a close agreement could not be expected.

Turning to the oxygen, the volume which is calculated to have been diffusing is obviously far in excess of the volume of carbon dioxide, and is indeed very large. The laboratory experiment with 100 grams of soil in the closed vessel showed that not only about 52 c.c. of oxygen disappeared when 31 c.c. of CO₂ was produced, but that nearly all the oxygen was assimilated in one way or another. The quantity of oxygen calculated to be diffusing, 0.454 c. dm. per day, is equivalent to $\frac{4.54}{40} = 0.131$ c. dm. per 100 grams of soil in 10 days, assuming that it was all required by the first 3 dm. (about 12") of soil. There is however reason to suppose that some oxygen is constantly diffusing into the sub-soil.

The next case for consideration is that of the green-manured soil of 1914 (Table VIII). The calculation yields the following quantities:—

Date ...	...	...	...	14-9-14	17-9-14	20-9-14
Porosity	...	...	...	0.215	0.107	0.159
Gas ...	...	...	C. dm per sq. dm. per day.			
N ...	...	...	...	0.7591	0.2082	0.4751
CO ₂ ...	...	...	...	0.1436	0.0023	0.0502
				—	—	—
				0.9027	0.2105	0.5253
				—	—	—
O ...	...	...	...	0.9619	0.2175	0.5457

Here, again, the process involves a diffusion of nitrogen and carbon dioxide from the soil into the atmosphere, and a diffusion of oxygen into the soil. The oxygen is largely in excess of the carbon dioxide. The quantities found to be diffusing at succeeding times varied greatly, which was to be anticipated from the rainfall conditions. Only light rain fell during the first three days after digging in the san hemp; heavy rain fell on the evening of 16th, thus

reducing the porosity of the soil very seriously; no further rain fell, and the porosity of the soil naturally increased again before June 20th, thus allowing increased quantities of gas to diffuse. In this instance all that one can do is to compare the calculated quantities of carbon dioxide with the amount of carbon in the san hemp. The san hemp was equivalent to 6.13 gram of dry plant per sq. dm. of soil surface, containing approximately 3.37 gram of carbon. The mean of the three quantities of carbon dioxide estimated to have been diffusing is 0.0658 c. dm. per day which is equal to 0.1295 gm. carbon dioxide or 0.0353 gm. carbon. Thus assuming a *uniform* oxidation of the san hemp, this would be complete in $\frac{3.37}{0.0353} = 95$ days.

It is well known that the leaf and more delicate parts of a green plant which is mixed with damp soil disappear—in India—very rapidly, but that the wood—cellulose and lignin—remain for much longer. Thus the rate of carbon dioxide formation which has been deduced from the rate of diffusion is quite in accord with what might be anticipated from a general knowledge of the subject, and provides an indirect check on the value of the porosity factor as deduced by Buckingham. The quantity of oxygen diffusing is again much in excess of that required for the carbon dioxide. Regarding the quantities of oxygen which are thus calculated to be diffusing, it must be realized that if they are too high, this could only be due to incorrectness of Buckingham's factor, and any alteration of this would affect all the gases equally. If then it is fair to conclude that the calculated amounts of carbon dioxide are what might be expected under the circumstances, those calculated for oxygen must be similarly admitted as near the truth. It is also to be recollected that the oxygen assimilated has been debited entirely to the upper soil, whereas the sub-soil may be, and probably is, absorbing oxygen also. The cause of this absorption (apart from CO_2 formation) is unknown, but it evidently exists.

The third set of quantities of diffusing gases which may be considered are those of the soil in the neighbourhood of growing crops. The gas analyses are set out in Table X. Here nitrogen, carbon dioxide and in some cases hydrogen were passing out of the soil, whilst oxygen diffused into it. The calculated quantities are set out in the accompanying Table XVI.

Here we have no extraneous evidence with which to compare these quantities. They vary on different dates in part according to the rainfall, and in part reflect the activities of the plant at different times. Large quantities of carbon dioxide are constantly produced and much larger quantities of oxygen are constantly absorbed, and these are similar in magnitude to those accom-

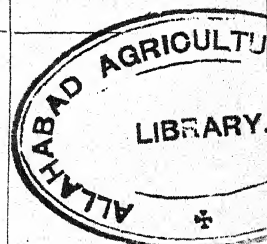
TABLE XVI.

*Volumes of gases diffusing from and into the soil near the roots of growing crops.**San Hemp.*

Date	...	...	27-7-14	30-7-14	3-8-14
Porosity	...	...	0.250	0.1954	0.1493
N	...	...	C. dm per sq. dm. per day 1.3750	0.5079	0.1373
CO ₂	...	...	0.3908	0.0301	0.0016
			1.7658	0.5380	0.1389
O	...	...	1.9060	0.5546	0.1413

Indigo.

Date	...	...	18-8-14	20-8-14	23-8-14
Porosity	...	...	0.135	0.212	0.1774
N	...	...	C. dm. per sq. dm. per day 0.4193	0.4425	0.2556
CO ₂	...	...	0.0212	0.1680	0.0191
H	...	...	0.4405	0.1236	0.0523
			0.4502	0.7341	0.3270
O	...	...	0.4502	0.7016	0.2982

*Maize.*

Date	...	...	6-9-14	8-9-14	10-9-14
Porosity	...	...	0.1465	0.194	0.159
N	...	...	C. dm. per sq. dm. per day 0.2552	0.1675	0.4872
CO ₂	...	...	0.0083	0.0244	0.0324
H	...	...	0.1164	0.1144	0.5196
			0.3799	0.3063	0.5342
O	...	...	0.3010	0.2331	0.5342

panying a recent application of green manure. In some cases they are larger. The quantity of hydrogen is notable.

There is one fact in relation to this subject that deserves very special consideration. The quantities of gas diffusing from or into the soil in the neighbourhood of growing crops, even in very wet weather, are quite as great as where a green manure had been recently dug in; they are also as great as, or greater than, where the fallow soil had become wetted by the early monsoon rainfall, and they are greater than the volumes which were diffusing through the fallow soil previous to the monsoon rainfall. In what respect then does the cultivation of the surface soil affect gaseous interchange? Naturally if land is disturbed by the plough or harrow, the gases in that particular stratum of soil have a much greater facility for diffusion than if the soil were not disturbed, but there is nothing to show that this operation affects the gases in the several feet of soil below it. Even supposing Buckingham's factor to be largely in error, the above argument would not be impaired, for whatever the actual quantities diffusing, the fact remains that the process goes on quite freely through the soil when thoroughly wet by the monsoon or at least sufficiently so for all needs of plant life. Although the proportion of oxygen was so small in the neighbourhood of the roots of the several crops, these were not only healthy but were indeed very fine ones. The value of good cultivation is of course an established fact, but that one of its chief advantages lies in a more perfect aeration of the soil is extremely doubtful.

CONCLUSION.

The information collected by the examination of soil gases has provided more precise information than has hitherto been obtained, principally on the following points:—

- (i) The volume of gas in soils under different moisture conditions has been obtained by *direct measurement* as distinct from that derived from the volumes of siliceous matter and water, and assuming the difference figures to be equal to the gas volume. The volume obtained by direct measurement has been found approximately equal to that obtained by the indirect calculation.
- (ii) The volume of condensed gas in the Pusa soil is so small that it cannot be estimated with accuracy and is certainly not greater than 4% of the total gas present.
- (iii) The volumes of gas during wet weather are naturally smaller than when the soil is dry because as water enters a soil, it displaces

some of the gas. The volume of displaced gas is not necessarily equal to the additional water, and the experimental results also show that 1 volume of water does not necessarily displace 1 volume of gas. At the same time the two approach equality.

- (iv) The whole of the gas is not displaced from a soil; indeed even during the wettest weather the proportionate volume of gas only falls to 15 or 20% or about one half the volume which is present during long periods of hot dry weather.
- (v) The soil gas of land which has been freshly treated with farm manure or green manure naturally contains a high proportion of carbon dioxide and a low proportion of oxygen, but it is evident from the information gained by operating with closed vessels (containing abundance of air) that were it not for the process of diffusion, the proportions would be very different from what they are.
- (vi) One of the most striking items of information which the investigation has provided is the composition of the gases in the neighbourhood of the roots of plants. Carbon dioxide has been known to be a constant accompaniment of plant growth, but whilst no definite numerical statements have been hitherto possible, the proportions which have been actually found must be considered high. More striking however is the low proportion of oxygen, and the presence of hydrogen has not hitherto been suspected under these conditions.

It is generally held that carbon dioxide is a product of the higher plant, but there is no experimental proof that this compound, although constantly present in the neighbourhood of the roots of crops, is not produced actually by lower organisms. Moreover the liberation of hydrogen gas must be due to the agency of an entirely different class of bio-chemical change from that concerned with the assimilation of oxygen or the production of carbon dioxide.

In the Memoir on Drainage (p. 97) I took the opportunity of calling attention to the very limited information in our possession regarding the associations of our crops with lower organisms, and the composition of the gases in the neighbourhood of crop-roots likewise emphasizes the importance of this subject.

- (vii) Although high proportions of carbon dioxide are frequently present in the gas as extracted from the soil, calculation shows that considerably the greater part is present in the dissolved state in the soil solution. We are ignorant of the relative physiological significance of the two states of this compound, but it is at least certain that from the chemical standpoint, the dissolved portion would be the active agent in any series of changes.
- (viii) It is quite easy to determine the O/A or N/A ratio in small amounts of soil gas within about 1/10 of the true value. The determination of these ratios although open to this error, has shown with great certainty that the chief changes in the soil have to do with the oxygen, whilst nitrogen-assimilation or nitrogen-evolution in dry land is at least so limited that it is usually difficult to detect.
- On the other hand, in cases like the gas from rice land, the argon determination demonstrates with certainty that most of the nitrogen is derived from the soil and manure.
- (ix) The amounts of the gases diffusing into or out of the soil have been calculated for a number of instances on the assumption that Buckingham's estimate of the effect of soil porosity is substantially correct. The result of these calculations is to show that the carbon dioxide diffusing out of the soil is much about what one would anticipate from independent evidence. At the same time very large amounts of oxygen pass into the soil, these being greater than might be expected from the amounts of carbon dioxide or nitrate which may be found concurrently. It is difficult to suggest a really satisfactory explanation for the utilization of such large amounts of this element.
- (x) Whether the correctness of these calculated amounts of diffusing gases be allowed or not, it is certain that diffusion of gases through soils at a depth of 12—15" is so efficient as to warrant the conclusion that cultivation of the surface soil is unnecessary for purposes of aeration. The well-established value of good cultivation must be referred to other causes.

PUSA,
May 4th, 1915.

A HY

ERRATUM.

MEMOIRS, CHEMICAL SERIES, Vol. IV, No. 4.
Page 145, last column of Table VII, *for 6.1 read 16.1*

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THE GASES OF SWAMP RICE SOILS.

PART III.

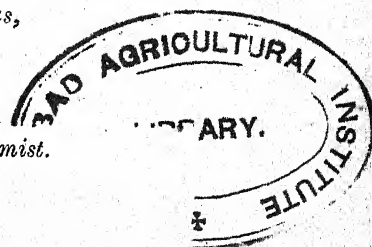
A HYDROGEN-OXIDIZING BACTERIUM FROM THESE SOILS.

BY

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AND

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PART I.

GENERAL.

IN the recent Memoir published by Harrison and Subramania¹ dealing with the relationship between the gases of Swamp Rice Soils and the organized film present on the surface of the soil, it was shown that the latter possessed the power of oxidizing hydrogen. This oxidation was further demonstrated to be due to the activities of certain bacteria, and crude cultures were obtained and their action studied. In that Memoir it was intimated that a pure culture of a specific bacterium had been obtained, and it is with this organism that the present Memoir deals.

The crude cultures were cultivated and studied in Kaserer's solution² under autotropic conditions, and it was naturally assumed that the pure bacterium would also exist under these conditions and be similar in character, if not identical, with that isolated and described by Kaserer.³ This, however,

¹ Harrison and Subramania. The Gases of Swamp Rice Soils, Part II, Their Utilization for the Aeration of the Roots of the Crop. *Mem., Dept. of Agri., India, Chem. Ser.*, vol. IV, no. 1.

²

K ₂ H PO ₄	...	0.05%
Mg SO ₄	..	0.02%
Am Cl	...	0.10%
NaHCO ₃	...	0.05%
Fe Cl ₃	...	trace.

³ Kaserer. *Cent. Bakt.* 2 abt, 15 (1905) p. 573, 2 abt, 16 (1906) p. 431.

did not prove to be the case, for the organism which has been isolated from these rice soils develops only very poorly in pure culture under autotrophic conditions and the oxidation of hydrogen only becomes prominent in the presence of small amounts of soluble organic matter.

On plating out the crude cultures on silica jelly, or washed agar media, containing the salts forming Kaserer's solution and incubating in an atmosphere consisting of a mixture of CO_2 , CH_4 , O and H exceedingly small colonies invariably developed which grew but slowly, but out of a large number specifically studied only one colony was found capable of oxidizing hydrogen under autotrophic conditions and even so its action was slight:—

TABLE I.

Showing the oxidizing action of the colony under autotrophic conditions.
cc. NT & P (Incubation period 9 days).

	Expt. I			Expt II		
	In the presence of CH_4			In the presence of CO_2		
	Before	After	Diff.	Before	After	Diff.
CO_2	.....	.....	.....	29.2	26.8	-2.4
CH_4	29.7	28.0	-1.7	.....	.....	.....
O	33.7	28.6	-5.1	33.1	28.8	-4.3
H	40.8	32.1	-8.7	40.0	31.6	-8.4
N	4.3	6.0	+1.7	4.2	4.9	+0.7

This culture grew fairly well on mineral agar medium, but microscopical examination revealed the fact that it was composed of a mixture of two different species of bacteria, one non-motile and the other smaller and a pseudomonas. All attempts to separate them by plating on mineral agar resulted in the production of colonies which had no action on hydrogen. The colonies thus isolated invariably contained the smaller organism present in the mixed culture and under these conditions it was not found possible to isolate the other bacterium.

A consideration of the above facts led to the conclusion that the hydrogen oxidation of the mixed culture was due either to two or more bacteria acting together in symbiosis, or that the particular bacterium to which the action could be ascribed was unable to exist in pure culture under autotrophic conditions. In order to test the latter assumption the mixed culture was inoculated into Kaserer's solution to which 0.1 % of sodium asparaginate was added and the amount of hydrogen oxidation again determined. It was at

once evident that the addition of this organic matter had led to an increased amount of oxidation.

TABLE II.

Showing oxidation of H by mixed culture in 0.1 Na. Asparaginate solution.
cc. NT & P (Incubation period 20 days).

	Before	After	Diff.
CO ₂	nil	0.3	+ 0.3
O	23.6	nil	- 23.6
H	63.1	15.7	- 47.4
N	9.8	14.4	+ 4.6
Total	96.5	30.4	- 66.1

This type of result confirmed the second supposition and the mixed culture was accordingly plated out on mineral agar, to which 0.1 % sodium asparaginate had been added, and incubated in an atmosphere of oxygen and hydrogen. Colonies developed of which a large number proved to possess the power of oxidizing hydrogen in the presence of soluble nitrogenous organic matter and which were found to consist of the larger non-motile bacterium previously referred to. These cultures were repeatedly re-plated in order to make perfectly certain that pure cultures were present, and the organism will hereafter be referred to as H_A. The motile bacterium associated with it in the mixed culture was designated as H_B.

The hydrogen oxidizing bacterium H_A thus isolated appears to be a new species. It is easily differentiated from Kaserer's organism, *B. pantotrophus*, as is shown in the following table :—

TABLE III.

Contrasting Bacterium H_A with *B. pantotrophus*.

	H _A	<i>B. pantotrophus</i>
Motility ...	absent	present
Flagellæ ...	absent	present
Colour on gelatine ...	white	yellow
Hydrogen oxidation ...	Practically absent under autotropic conditions; but pronounced in the presence of soluble organic matter.	Very pronounced under autotropic conditions but inhibited by the presence of soluble organic matter.

The characteristics of this bacterium are as follow :—

Morphological characteristics. Small bacterium, about 1.4μ long and 0.5μ broad which stains readily with ordinary aqueous stains, but the staining is however very uneven. Does not stain by Gram's method. It is non-motile and flagellæ and spores have not been demonstrated. In old cultures involution forms are common.

Gelatine stab (20% gelatine). A white, somewhat restricted surface growth is formed, which has a shiny wrinkled surface. Liquefaction has occasionally been noticed after several weeks. The growth along the line of the needle is poor and restricted to the portion near the surface of the gelatine.

Agar plates. White round colonies with entire edge and shiny wrinkled surface.

Potato. Moist shiny growth, very restricted and slightly raised at the edges. At first the colour is that of the medium but later it becomes a pale buff.

Broth cultures. Slight turbidity often with characteristic zoogloea masses floating in the liquid, later a tough pellicle develops. Indol is not produced.

Nitrate broth. Nitrates are not reduced and no gas is formed.

Glucose, Lactose, and Sucrose broth. No fermentation, neither acid nor gas being produced. Characteristic floating zoogloea masses are formed.

Milk is unchanged.

Chemical activities. The bacterium grows exceedingly poorly in mineral solution, or on solid mineral media under autotrophic conditions in the presence of CO_2 , 2CH_4 , H and O and at the same time only very small quantities of hydrogen disappear. But although practically inactive under these conditions yet in association with the bacterium H_2 and water bacteria autotrophic oxidation of H readily takes place. In this case, the bacteria are evidently existing together in a state of symbiosis, the foreign organisms assimilating the carbon-dioxide with the formation of organic matter which, in turn, enables the specific bacterium to carry out its functions.

Experiments under autotrophic conditions were found to be unsatisfactory and discordant unless all traces of soluble organic matter were eliminated. It was found necessary to clean all apparatus with hot chromic acid mixture, to use only re-distilled water and to carefully re-crystallize all the salts used.

This bacterium grows quite well upon all ordinary organic nutrient media and under these conditions is able to oxidize hydrogen. This oxidation is evidently an energy source, but the intensity of the action is dependent not

only on the kind, but also upon the quantity of organic matter present. A large proportion of organic matter is particularly objectionable from this point of view as then the bacterium exists mainly upon the organic matter and the oxidation of hydrogen reaches a minimum.

The best results are obtained with solutions containing from 0.01 to 0.03% of such substances as peptone, nutrose, sodium asparaginate, etc. The organism is able to utilize ammonia and nitrates as the nitrogen source in presence of glucose, but in these circumstances little hydrogen oxidation takes place, and neither are nitrites nor nitrogen produced from the nitrate. It would almost appear as if the hydrogen oxidation went hand in hand with assimilation of organic nitrogenous food materials.

Association with H_B and water bacteria is just as effective in increasing the oxidizing action of the bacterium in organic media as was found to be the case under autotrophic conditions. In fact, the only cases in which the reaction has been carried out to completion have occurred with such associations and the efficiency of these symbiotic relationships under natural conditions is thereby emphasized.

The main difficulty experienced during the investigation was due to the fact that the bacterium rapidly lost all oxidizing power when continuously cultivated on organic media. To obviate this, two methods were adopted, namely, (1) to grow the cultures on mineral agar to which not more than 0.03% sodium asparaginate was added and (2) to cultivate the mixed culture of H_A and H_B under autotrophic conditions and to isolate the former in asparaginate agar as required.

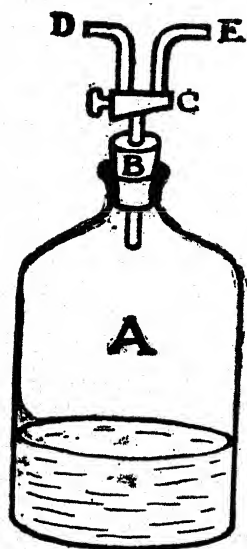
The functions of these oxidizing bacteria with regard to rice soils have been fully dealt with in the Memoir by Harrison and Subramania previously referred to and there is, therefore, no occasion to refer to it again here except to point out that they are the means of conserving the energy dissipated by the decay of organic matter in these soils, and making that energy, or at least part of it, available for the crop.

PART II.

EXPERIMENTAL.

Method of experiment. The experiments with the crude cultures were carried out with the apparatus and in the manner described in the Memoir previously quoted. But the impossibility of obtaining a sufficiency of similar apparatus to enable a large number of experiments to be carried out simultaneously compelled the adoption of a simpler method of experiment.

The apparatus used throughout the experiments dealt with in the sequel is shown in the annexed sketch.



The neck of a bottle A was closed with a rubber cork B through which a three-way glass stopcock C was inserted, the exit tubes D and E of which were plugged with sterile cotton wool. About 30 cc. of the nutrient solution experimented with was introduced into the bottle and the cork and stopcock then inserted and the whole sterilized in the autoclave.

The liquid was inoculated by momentarily removing the cork, and the exit tube D was then connected to an air pump and the exit tube E to a reservoir containing the mixed gases. The air was then pumped out of A until the liquid in it boiled. Gas was then admitted through E from the reservoir and the bottle was again evacuated. This was repeated 3 times in all, so as to make perfectly certain that the bottle was filled with the mixed gases.

After inoculating the bottles were stored under water and incubated at 34°C. At the end of this period the bottle was wiped dry and weighed and then the tap C was opened under water to allow the internal pressure to adjust itself. After bringing the surfaces of the internal liquid and external water to the same levels, the tap C was closed and the apparatus again wiped dry and weighed. Any difference in weight was equivalent to an alteration in the

volume of the gas in the bottle, which was reduced to NT & P both before and after the experiment. Finally, the gas was removed and analysed and any changes in composition which it had undergone noted. Knowing the composition and volume of the gas before and after the experiment it was possible to calculate the alteration in the volumes of the component gases.

EXPERIMENTS UNDER AUTOTROPIC CONDITIONS.

(i). H_A in pure culture.

A very large number of experiments were carried out in which the bacterium was cultivated in Kaserer's solution in an atmosphere of CO_2 , CH_4 , O and H. As before indicated, in order to obtain concordant results it was found necessary to use redistilled water and carefully purified chemicals so as to obviate the presence of small traces of soluble organic matter which caused the bacterium to behave abnormally. It was also necessary to clean the apparatus used with chromic acid mixture.

The following table shows the type of result obtained :—

TABLE IV.

*Showing the action of H_A in pure culture under autotropic conditions.
cc. NT & P.*

Experiments	Expt. I			Expt. II			Expt. III		
Days incubation	10			20			10		
	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
CO_2	27.5	21.6	-5.9	2.0	1.7	-0.3	26.3	20.2	-6.1
O	57.5	51.3	-6.2	38.4	35.5	-2.9	32.1	27.1	-5.0
H	53.9	54.3	+0.4	48.9	50.5	+1.6	28.2	19.4	-8.8
CH_4	3.9	3.5	-0.4	42.6	39.4	-3.2	20.5	18.7	-1.8
N	4.2	4.1	-0.1	13.0	10.6	-2.4	27.8	25.6	-2.2
Total	147.0	134.8	-12.2	144.9	137.7	-7.2	134.9	111.0	-23.9

The bacterial growth in the bottles was exceedingly poor in all cases. From these results it is concluded that the bacterium possesses very slight powers of assimilating CO_2 and CH_4 under autotropic conditions, but that its power of oxidizing hydrogen is very small.

(ii). *H_A symbiosis with other organisms.*

The fact that the mixed culture of the bacteria *H_A* and *H_B* could, under autotrophic conditions, oxidize hydrogen led to the study of their action under symbiotic conditions. In all cases, considerable oxidation occurred and much carbon dioxide disappeared.

TABLE V.

Showing the effect of H_A in symbiosis with H_B.

cc. NT & P.

	H _B alone 14 days			H _A + H _B 20 days		
	Before	After	Diff.	Before	After	Diff.
CO ₂	49.8	30.5	-19.1	29.4	7.9	-21.5
O	75.2	85.2	+10.0	35.2	nil	-35.2
H	115.4	115.5	+0.1	103.0	7.5	-95.5
CH ₄	32.4	27.7	-4.7	17.9	16.5	-1.4
N	14.3	17.0	+2.7	27.5	31.4	+3.9
Total	286.9	275.9	-11.0	213.0	63.3	-149.7

It would thus appear that the bacterium can exist under autotrophic conditions in symbiosis with bacteria capable of assimilating either CO₂ or CH₄.

EXPERIMENTS UNDER HETEROTROPIC CONDITIONS.

The early experiments with the bacterium were carried out in solutions containing only very small amounts of organic matter varying from 0.01 to 0.05% but in no case, even with 30 days incubation, did the action proceed to completion, *i.e.*, when either all the H or O was used up. It was thought that by increasing the proportion of organic matter such would occur, but in reality it was found that the amount of hydrogen oxidized was greatly reduced. These facts led up to a study of the effect of varying proportions of organic matter upon the course of the reaction.

Cultures grown in Botkin Flasks with different kinds of organic matter gave different results. With substances of the type of peptone and nutrose a very good growth was obtained and the rate of oxidation was rapid. Sodium

asparaginate and asparagin gave inferior results, but still the action was marked. Glucose in conjunction with ammonium salts or nitrates yielded very inferior results and the hydrogen oxidation was very small. Oxidation of hydrogen by the bacterium appears to be only efficient when organic nitrogen is present although assimilation of N takes place from inorganic substances.

Solutions containing sodium asparaginate being entirely synthetic in character and the organic matter of a comparatively simple type experiments were first instituted with this substance to test the effect of different proportions. Later similar series were carried out with peptone.

(i) *The Effect of Varying Proportions of Sodium Asparaginate on the Oxidation of Hydrogen.*

With proportions of sodium asparaginate varying from 0.01 to 0.03% the oxidation of hydrogen proceeds smoothly and is not complicated by the presence of other actions. With stronger solutions oxidation of organic carbon with the production of carbon dioxide takes place in addition.

The following is the record of an experiment carried out in Kaserer's solution containing varying proportions of sodium asparaginate:—

TABLE VI.

Showing the action of the *Bacterium* in solution containing different proportions of sodium asparaginate.

No.	1			2			3			4			5		
	0.5			0.25			0.1			0.05			0.03		
% asp.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
CO ₂	1.4	26.9	+25.5	1.1	11.8	+10.7	1.1	10.3	+9.2	1.1	3.2	+2.1	3.6	4.4	+0.8
O	115.1	43.6	-71.5	95.4	63.6	-31.8	89.2	68.2	-21.0	94.2	81.4	-12.8	107.5	83.8	-23.7
H	151.0	119.0	-32.0	125.0	101.5	-23.5	117.0	98.2	-18.8	123.5	97.2	-26.3	152.3	100.5	-51.8
Total	267.5	189.5	-78.0	221.5	176.9	-44.6	207.3	176.7	-30.6	218.8	181.8	-37.0	263.4	188.7	-74.7

In the following table the important relationships of this experiment are brought forward :—

Strength of solution	0.5	0.25	0.1	0.05	0.03
Decrease in volume per 100 cc. of original gas ...	29.2	20.1	14.8	17.7	28.3
Production of CO ₂ ..	9.6	4.8	4.4	1.5	0.3
Disappearance of O ..	26.8	14.3	10.1	5.8	9.0
Disappearance of H ..	11.9	10.6	9.1	12.1	19.6
O/H Ratio ...	1/45	1/74	1/9	1/2.05	1/2.18

Thus the bacterium in dilute solution brings about only oxidation of hydrogen, whereas, with increasing strengths more and more carbon dioxide is produced and this is naturally followed by an increasing consumption of oxygen. The consumption of hydrogen, which can be taken to measure the amount of hydrogen oxidation, decreases at first with increasing amounts of organic matter and reaches a minimum with about 0.1%. Greater strengths than this bring about an increased hydrogen consumption but not in proportion to the oxygen consumption or the carbon-dioxide production. A similar phenomenon will be noticed when the effect of peptone is considered.

The best results so far as purely hydrogen oxidation is concerned are obtained with solution containing about 0.02% sodium asparaginate but in no case has the reaction been observed to go to completion. Complete removal of the hydrogen or oxygen is, however, attained with mixed cultures with water bacteria. The following results were obtained when a few drops of the water used for irrigating the rice fields were added to the experiment bottle.

TABLE VII.
Showing action of the Bacterium in association with Water Bacteria.
cc. NT & P.

	H _A and water bacteria			H _A alone		
	Before	After	Diff.	Before	After	Diff.
CO ₂	1.5	0.4	- 1.1	1.6	2.8	+ 1.2
O	45.5	13.5	- 32.0	48.3	39.0	- 9.3
H	64.4	nil	- 64.8	67.2	51.1	- 16.1
N	1.0	5.1	+ 4.1	1.0	8.3	+ 7.3
Total ...	112.8	19.0	- 93.8	118.1	101.2	- 16.9

Consequently, as under autotrophic conditions, the bacterium reaches its highest efficiency when living in symbiosis with other organisms.

(ii) *The Effect of varying Proportions of Peptone on the Oxidation of Hydrogen.*

Several series of experiments with varying amounts of peptone were carried out in a similar manner to those with sodium asparaginate. The record of one such series is given below :—

TABLE VIII.

Showing the effect of varying proportions of peptone on the oxidation of hydrogen, cc. NT & P.

% Peptone	0.5			0.25			0.125			0.062			0.031		
	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
CO ₂	1.0	0.8	- 0.2	1.0	4.1	+ 3.1	1.0	9.8	+ 8.8	0.9	2.8	+ 1.9	1.0	1.9	+ 0.9
O	55.7	45.1	- 10.6	55.3	40.8	- 14.5	53.4	16.4	- 37.0	51.5	11.5	- 40.0	55.3	31.3	- 24.0
H	84.5	60.5	- 24.0	84.1	68.3	- 15.8	81.0	48.1	- 32.9	74.3	13.6	- 64.7	84.0	40.5	- 43.5
N	2.8	3.1	+ 0.3	2.7	4.7	+ 2.0	2.6	4.8	+ 2.2	2.5	3.7	+ 1.2	2.7	3.8	+ 1.1
Total ...	144.0	109.5	- 34.5	143.1	117.9	- 25.2	138.0	79.1	- 58.9	133.2	31.6	- 101.6	143.0	77.5	- 65.5

These results when collated in a similar way to the ones with sodium asparaginate yield the following comparison:—

	0.5	0.25	0.125	0.062	0.031
Disappearance of gas per 100 cc. of original volume	24.0	17.6	41.7	87.0	45.8
Production of CO ₂ .. Do.	-0.1	2.0	6.4	1.4	0.7
Disappearance of O .. Do.	7.4	10.1	26.8	30.0	16.9
Disappearance of H .. Do.	16.6	11.0	23.9	48.6	30.8
$\frac{H}{O}$ ratio	$\frac{2.2}{1}$	$\frac{1.1}{1}$	$\frac{0.9}{1}$	$\frac{1.6}{1}$	$\frac{1.9}{1}$

These results show a very similar variation in the effect of the organic matter on the hydrogen oxidation to those with sodium asparaginate. The main difference being that from peptone there appears to be comparatively little CO₂ production but this fact, however, makes clearer the relative intensity of the hydrogen oxidation.

(iii) *The Action of the Bacterium on Hydrogen with Ammonia and Nitrates or the Nitrogen source.*

The results previously considered have been those in which organic nitrogen supplied the necessary nitrogen, but the ones now considered deal with the action when the nitrogen is derived from purely mineral sources.

The first results given are those in which ammonia alone is the nitrogen source and glucose providing the carbon source.

TABLE IX.

Showing action of Bacterium H_A with ammonia as the nitrogen source and glucose as the carbon source.

cc. NT & P.

	Before	After	Diff.
CO ₂ ..	0.3	11.0	+10.7
O ...	69.2	48.3	-20.9
H ...	84.0	72.3	-11.7
N ...	3.7	2.7	- 1.0

The organism can evidently assimilate ammonical N in the presence of glucose and a fair amount of hydrogen is oxidized. There is also a considerable production of CO₂ from the glucose.

TABLE X.

Showing action of Bacterium with nitric nitrogen as the nitrogen and glucose as the carbon source.

	Before	After	Diff.
CO ₂	0.3	7.2	+6.9
O	60.6	55.8	-4.8
H	73.8	72.1	-1.7
N	3.2	4.2	+1.0

A fairly good growth occurred, but the results clearly show that under these conditions little hydrogen is oxidized. At the same time no nitrous acid was produced.

COIMBATORE,
September 15, 1915.

PREFACE.

THE experiments detailed in the following pages have been made under conditions obtaining in South India. It is possible that the immediate results vary somewhat under other conditions ; but the broad conclusions drawn therefrom, we believe, will hold good generally.

We beg to acknowledge our indebtedness to Dr. W. H. Harrison, Government Agricultural Chemist, Madras, not only for the facilities kindly afforded us for conducting the experiments but also for the very kind advice and help so willingly given in spite of much personal inconvenience to himself.

COIMBATORE,
November, 1915.

B. V. N.
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SOME FACTORS AFFECTING THE COOKING OF DHOLL (*CAJANUS INDICUS*).

BY

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Red gram or Pigeon pea (*Cajanus indicus*) is extensively cultivated in India as a food-crop and is regarded as third in rank of importance among the leguminous seeds.¹ Unlike peas and some other beans which are cooked green, the red gram is cut after it is ripe and allowed to dry in the sun. The seeds are afterwards broken into dhol, the husk removed, and then cooked.

In Southern India the gram seeds, after drying, are first mixed with red earth and water and allowed to steep for one night and then dried in the sun before being broken into dhol. For use as food this dhol is boiled in water and afterwards eaten in conjunction with other foodstuffs such as rice and vegetables. In the South Indian dietary it is this pulse which is chiefly depended upon by vegetarians to increase the nitrogenous content of rice-foods.

The cooking qualities of different dholls vary considerably, some requiring long continued boiling to reach the desired stage whilst others cook quickly and the object of the purchaser is naturally to acquire the latter type. Apart from the cooking qualities of different dhol varieties it is a point of general belief that the quality of the water used for boiling has a considerable effect upon the rate of cooking and it is mainly with this aspect of the case that the experiments detailed in the following pages are concerned.

¹ Watt. *Commercial Products of India*, 1908.

In determining the various factors which affect the rate of cooking of dholl it is of course impossible to examine all possibilities and this enquiry has been limited to the following :—

- I. The effect of the composition of the water upon the rate of cooking.
- II. (a). The influence of the fat content on the rate of cooking.
(b). Differences in the rates of cooking due to variety.
(c). Differences in the rates of cooking due to methods of preparing the dholl.
- III. The influence of various salts on the liquefaction of starch.

PART I.

THE EFFECT OF THE COMPOSITION OF THE WATER UPON THE RATE OF COOKING.

Before undertaking a detailed enquiry upon the effect of the different salts usually found in South Indian waters upon the rate of cooking, it was deemed desirable to ascertain whether or not the rate of cooking varied with waters of different composition. For this purpose water of very different quality derived from five sources was used. The composition of these waters is shown below :—

TABLE I

Showing the composition of the various waters taken for experiment.

(Parts per 100,000)

Name of well	CaCO ₃	MgCO ₃	Na ₂ CO ₃	CaSO ₄	MgSO ₄	Na ₂ SO ₄	CaCl ₂	MgCl ₂	NaCl	Total solids
Joseph's well	12.49	6.06	1.40	...	...	1.82	...	...	6.35	33.0
No. 57 well	41.04	0.82	...	...	48.10	...	...	4.84	135.19	264.0
College well	33.02	4.22	...	...	29.47	...	...	4.72	89.03	160.0
Owaraka well, Madras	15.01	...	...	8.41	56.23	...	...	41.97	285.62	560.0
Kaladindy Ravu drain water, Kistna	12.01	...	...	59.00	66.00	...	...	137.00	928.00	1225.0

In testing the effect of these different waters the procedure followed was of a purely empirical character. The dhol used was obtained from the Central Farm, Coimbatore, and was carefully sorted out so as to exclude all bad or damaged ones, and in addition was passed through a 4 m.m. sieve so as to obtain a sample of approximately uniform size. Twenty grammes were added to 250 c.c. of water contained in a beaker and the whole boiled until the cooking was judged to be complete. During this process care was taken to maintain the water at the same constant level and for the sake of comparison an experiment was carried out with distilled water. The dhol was judged to be properly cooked when it could be easily crushed between the fingers.

The times taken to cook the dhol by the different waters were as follow :—

Distilled water	—	...	...	37 minutes.
Joseph's well	...	...	...	37 „
College well	...	...	...	48 „
No. 57 well	...	...	...	50 „
Dwaraka well	...	...	over	60 „
Kaladindy drain water	...	...	„	75 „

There can, therefore, be no doubt that the presence of dissolved salts in water materially affects the time taken to cook the dhol.

In South India it is a common practice to add a pinch of sodium bicarbonate to the water as this is found to materially accelerate the rate of cooking. Consequently the above experiment was repeated after adding a pinch of this substance to the several waters. The times taken were then as follow :—

Distilled water	...	...	...	20 minutes.
Joseph's well	...	...	...	20 „
College well	...	...	...	23 „
Dwaraka well	...	...	...	40 „
Kaladindy drain	...	...	...	50 „

It becomes evident, then, that the presence of an alkaline substance in the water materially accelerates the rate of cooking.

The rate of cooking of dhol appears to depend upon two factors, namely, the amount and the kind of dissolved substances present. A series of experiments was carried out with the object of determining the effect of different classes of salts upon the rate of cooking. These tests were carried out in beakers as described above. The results are given in Table II.

TABLE II

Showing the rate of cooking of dhol in different solutions of varying strengths in minutes.

Strength of solution in parts per 100,000	10	20	50
Distilled water ... ..	...	17	...
MgCl ₂	20	23	24
NaCl	18	24	24
CaCl ₂	24	32	46
Na ₂ CO ₃	18	18	16

One curious result obtained was the retarding action of CaCO₃ suspended in distilled water. With amounts equal to 10, 20, 50 and 100 parts per 100,000 the corresponding times were 18, 21, 35 and over 86 minutes respectively.

These results bear out the conclusion that the rate of cooking with neutral salts varies with the kind and the amounts used, the effect being a retardation, whereas, in the case of alkaline salts the rate of cooking is accelerated, the acceleration increasing with the concentration.

The foregoing experiments were only of a preliminary nature and were of a rough and ready type, so that they could only be looked upon as giving approximate results. In order to obtain more accurate data, particularly with reference to the mode of action of the various salts, some other method of experiment was desirable.

After a number of different procedures had been tried the following was selected as giving the most accurate results. During the process of cooking, a certain amount of disintegration of the dhol takes place resulting in the solution of amylaceous material. The basis of comparison taken in the following experiments was the amount of amylaceous matter passing into solution when the dhol was boiled with different solutions for a fixed time. In carrying out these determinations, 250 c.c. of distilled water or of an aqueous solution were introduced into a litre flask closed with a cork through which passed a

reflux condenser. The liquid was raised to the boiling point and maintained there whilst the condenser served to keep the volume constant. When the rate of boiling was quite uniform the cork was momentarily removed and ten grammes of dhol added and the boiling continued for sixteen minutes, a period of time which experience showed was long enough to give a differentiation between the degrees of cooking with the various solutions and to give comparable results with duplicates.

At the end of this period the flask was rapidly cooled and the contents were then filtered through fine muslin so as to remove the residual dhol. 100 c.c. of the filtrate were transferred to an Erlenmeyer flask, 20 c.c. of pure HCl of sp. gr. 1.125 were added and boiled for one hour so as to hydrolyse the amylaceous matter present. As in the previous case, a reflux condenser served to maintain the volume constant. The flask was then rapidly cooled and after making slightly alkaline with caustic soda 20 c.c. of alumina cream were mixed with the contents. The volume was made up to 250 c.c. with distilled water and the liquid filtered. The reducing sugar present was determined volumetrically with Fehling's solution and the result calculated as starch.

In the same way by determining the amount of nitrogen in the residual dhol it is possible to estimate the proteid matter which had passed into solution and thus determine the effect of the solutions on the proteids of the grain. Thus the complete series of determinations for a single experiment can be made to cover the following points :—

1. Weight of dhol taken as dry matter.
2. Weight of dry matter left after boiling.
3. Weight of proteids in original dhol.
4. Weight of proteids in dhol after boiling.
5. Weight of starch passing into solution.

The difference between 1 and 2 gives the amount of dry matter removed during the process of boiling and that between 3 and 4 the amount of proteids passing into solution, so that it is possible to compare the action of different salts on both the starch and proteids present.

The solutions used were of strengths $\frac{N}{100}$ and $\frac{N}{200}$. The results obtained are given in Table III.

TABLE III

Showing comparative action of different salts on the cooking of dholl.

Solutions	N 100						N 200							
	Residue after boil- ing	Matter removed by boiling	Total	Proteid matter in unboiled dholl	Proteid matter in residual dholl	Proteid matter re- moved by boil- ing	Starch removed by boiling	Residue after boil- ing	Matter removed by boiling	Total	Proteid matter in unboiled dholl	Proteid matter in residual dholl	Proteid matter re- moved by boil- ing	Starch removed by boiling
Water ...	6.67	3.33	10.00	2.33	1.71	0.62	0.70	6.67	3.33	10.00	2.33	1.71	0.62	0.70
Sodium chloride	6.72	3.28	10.00	2.33	1.74	0.59	0.60	6.73	3.27	10.00	2.33	1.68	0.65	0.63
Magnesium chloride	7.46	2.54	10.00	2.33	1.89	0.44	0.50	7.29	2.71	10.00	2.33	1.85	0.48	0.53
Calcium chloride	7.80	2.20	10.00	2.33	1.94	0.39	0.43	7.61	2.39	10.00	2.33	1.90	0.43	0.46
Calcium hydrogen car- bonate ...	7.39	2.61	10.00	2.33	1.79	0.54	0.49	7.30	2.70	10.00	2.33	1.76	0.57	0.50
Sodium carbonate	5.19	4.81	10.00	2.33	1.27	1.06	0.77	6.01	3.99	10.00	2.33	1.53	0.81	0.71
Caustic potash	3.80	6.20	10.00	2.33	0.86	1.47	1.13	5.39	4.61	10.00	2.33	1.82	1.01	1.03
Hydrochloric acid	7.37	2.63	10.00	2.33	1.90	0.43	0.59	7.29	2.71	10.00	2.33	1.82	0.51	0.54
Sodium sulphate	6.51	3.49	10.00	2.33	1.59	0.74	0.70	6.82	3.18	10.00	2.33	1.67	0.66	0.68
Magnesium sulphate	7.34	2.66	10.00	2.33	1.86	0.47	0.51	7.14	2.86	10.00	2.33	1.75	0.58	0.54

Chart I. showing relative solution of solid matter

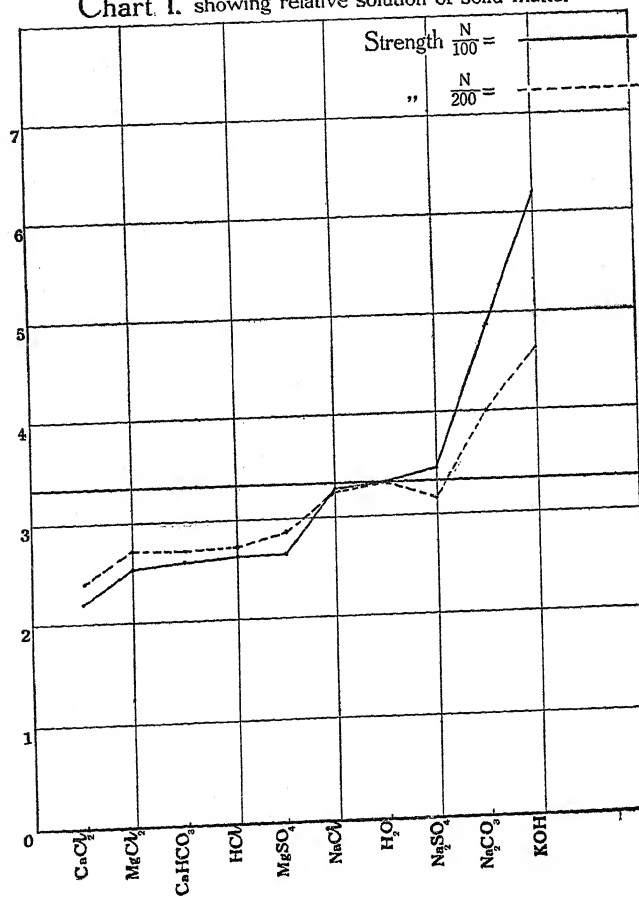


Chart II. showing relative solution of Proteid

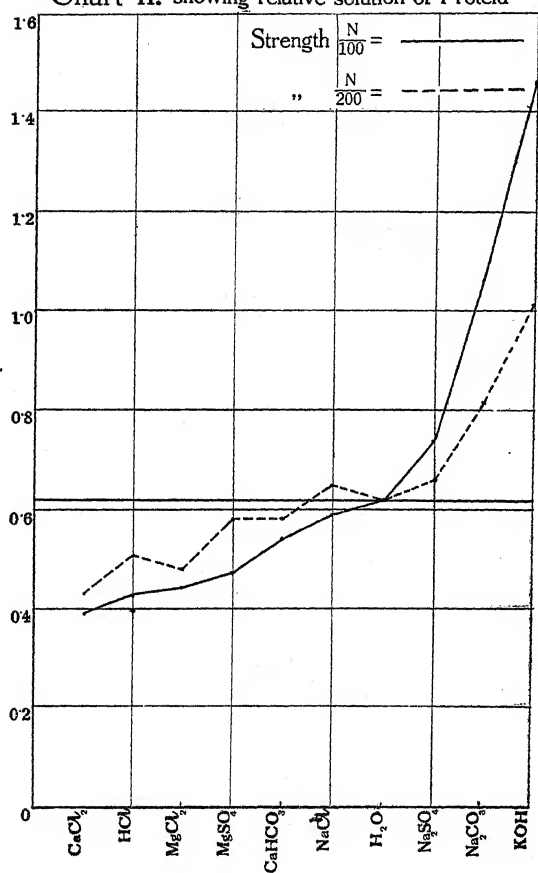
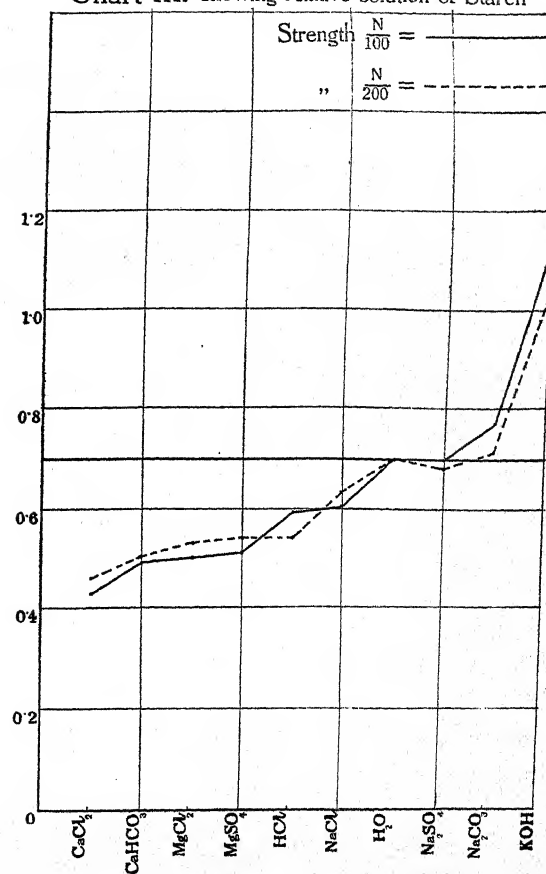


Chart III. showing relative solution of Starch



These results bear out the previous conclusion that the rate of cooking is affected by the character and the amount of salt present. This is clearly shown in charts I, II and III where the values obtained are plotted out in the form of graphs.

It will be seen that certain salts retard the rate of cooking as compared with distilled water, whereas others cause an acceleration. This effect is evidently due to the influence the salts exert in modifying the solvent action of the water. Those salts which cause retardation are those which decrease the solvent action of the water and *vice versa*.

As would be expected on this basis, the general effect of increasing concentration in the case of those substances which cause retardation is to increase the amount of retardation, whereas those which bring about an acceleration do the reverse. As a general rule, chlorides, sulphates and carbonates cause retardation, whereas alkalies and alkaline carbonates bring about an acceleration. HCl, curiously enough, acts as a retarding agent. The broad conclusion to be drawn is that hard waters retard the rate of cooking in proportion to the amount of salts they contain and that alkaline waters accelerate it.

The mode of action of the substances studied is not, however, merely due to a solution of the dhol substance quite independent of its constitution, but is partially due to a selective solvent action with respect to the proteids and starch.

This is clearly shown by a comparison of the relative amounts of starch and proteid which go into solution during the boiling process.

TABLE IV
Showing $\frac{\text{Starch}}{\text{Proteid}}$ ratio in the solutions.

Solutions	N/100	N/200
Na ₂ CO ₃	0.73	0.88
KOH	0.77	1.02
CaHCO ₃	0.91	0.88
Na ₂ SO ₄	0.94	1.03
NaCl	1.02	0.97
MgSO ₄	1.09	0.93
CaCl ₂	1.10	1.07
H ₂ O	1.12	1.12
MgCl ₂	1.14	1.10
HCl	1.37	1.06

With N/100 strengths water has a ratio of 1.12 and this is closely approximated only by CaCl₂ and MgCl₂, and NaCl and MgSO₄ do not vary greatly

from this figure, showing that the solvent action in each case has been of a very similar nature. HCl, however, gives a much higher ratio, showing that the action of this substance is to increase the proportion of starch dissolved. On the other hand, KOH and Na_2CO_3 have greatly increased the proportion of proteid matter going into solution and the same holds good to a lesser degree for CaHCO_3 and Na_2SO_4 .

These relations account for the discrepancies shown by HCl in Chart III.

The fact that the substances which have the greatest effect in accelerating the rate of cooking are those which exert a proportionately greater solvent action on the proteids than on the starch leads to the general conclusion that it is the rate at which the proteid goes into solution which is the determining factor and that substances which greatly accelerate this rate also accelerate the rate of cooking and *vice versa*. This view is strengthened by the fact that the substances which retard the rate of cooking most are substances which are precipitants for many proteids.

With the weaker strengths of N/200 the various ratios more nearly approximate to that of water, so that the relationships brought out above are not so marked. Nevertheless, they offer a general support to the view expressed.

The conclusions arrived at in this portion of the investigation may be summarized as follow :—

1. Dissolved salts, such as are found in natural waters, exert a marked influence on the time taken to cook dholl.
2. Calcium and magnesium salts and the chlorides of hydrogen and sodium exert a strong retarding effect, whereas alkalies and alkaline carbonates have the reverse action.
3. Whether the action exerted by any salt is a retardation or an acceleration, the effect is approximately proportionate to the concentration, *i.e.*, the harder the water, the slower is the rate of cooking.
4. That the addition of sodium bicarbonate or sodium carbonate to a hard water materially hastens the cooking.
5. The rate of cooking of dholl is approximately proportionate to the rate of solution of the dholl substance, *i.e.*, to the rate of solution of the proteid and starch.
6. The proportion of proteid to starch dissolved is not constant but varies with different solutions. Alkalies and alkaline carbonates

dissolve a greater proportion of proteid than starch as compared with pure water whereas hydrochloric acid dissolves a greater proportion of starch. In addition, alkalies and alkaline carbonates greatly accelerate the rate of cooking.

7. The rate of solution of the proteid appears to be the factor which mainly controls the rate of cooking.

PART II.

MISCELLANEOUS OBSERVATIONS RELATING TO THE COOKING OF DHOLL.

(a). *The influence of the fat content.*

In the previous section the influence of the various salts on the rates of solution of the proteid and starch was mainly considered. But there remains the possibility that the accelerators of the type of Na_2CO_3 and KOH act by saponifying the fat of the food stuff.

In order to test this point a sample of dholl was extracted for 15 days with successive quantities of ether. It was then air dried and boiling tests with distilled water were made in comparison with untreated dholl. The extraction removed 72 % of the fat originally present. The results obtained were as follow :—

Starch extracted per 100 grm. of dholl.

	A	B
Extracted dholl	5.85	6.50
Unextracted dholl	6.25	6.60

It is evident that the removal of the fat has, if at all, only a very slight effect on the rate of cooking and that this effect is one of retardation.

It must therefore be concluded that the fat content of dholl plays a very unimportant part with regard to the rate of cooking.

(b). *The cooking rates of different dholls.*

It has been previously mentioned as a matter of common observation that dholls from different localities vary considerably in their rates of cooking and it was thought desirable to test this point by the methods adopted by us. A number of dholls from diverse localities were obtained and their several rates of cooking were determined by boiling a given weight with distilled water

for a fixed period as previously described and estimating the amount of amylaceous matter passing into solution.

TABLE V

Showing rates of cooking of various dholls.

A		B	
Source	Starch extracted per 100 grm.	Source	Starch extracted per 100 grm.
Vallam ...	5.55	Coimbatore ...	6.41
Mayavaram ...	5.93	Vizagapatam ...	6.50
Karur ...	6.49	Godavari (In- terior) ...	6.75
Panruti ...	6.76	Panruti ...	6.97
Pallapalayam ..	6.92	Coconada ...	7.00
Gulbarga, pale ...	7.00		
Gulbarga, red ...	7.17		

The figures bear out the common observation that different dholls vary in their rates of cooking.

The dholls under A were purchased as such and no information could be obtained with regard to the method of their preparation. This, as will be seen later, has some influence on the rate of cooking and the differences noticed are possibly partly due to differences in treatment as well. The figures under B refer to dholls prepared from gram with no preliminary treatment.

(c). *On the methods of preparing the dholl from the whole grain.*

The dholl as used for purposes of cooking is usually prepared by mixing the grain with water and red earth to a pasty mass and allowing the heaped up mass to remain in that condition for a certain number of hours after which it is spread out and sun-dried. It is then freed from the red earth, husked and the cotyledons separated, the latter forming the dholl. It is commonly believed that the duration of this soaking process is an important factor in determining the cooking qualities of the dholl and at the same time some importance is attached to the quality of water used in this process.

This treatment, no doubt, produces incipient germination and thus affects, to some extent, the character of the constituents and the rate of cooking. It is also conceivable, in view of our results, that the quality of the water used would also have some effect. To test these points red gram as obtained from the field at the time of harvesting was subjected to the usual

treatment with red earth and distilled water for varying periods of time and the rate of cooking of the products compared with an untreated sample. The results obtained are as follow :—

Treatment	Starch extracted per 100 gm.
Untreated	6.71
Treated for 8 hours	6.15
„ 16 hours	6.10
„ 24 hours	6.51

It is evident that this practice is not justified, for it has led in all cases to a distinct retardation in the rate of cooking.

The effect of salts present in the water was contrasted in a similar manner with the following results :—

Treatment	Starch extracted per 100 gm.
Soaked in distilled water for 16 hours	6.59
Soaked in N/100 CaCl_2 solution	6.52
„ N/100 Na_2CO_3 solution	6.84

It is evident that the action of CaCl_2 is to retard the rate of cooking, whereas Na_2CO_3 accelerates it, so that the use of alkaline waters or the addition of sodium carbonate to the water used would be beneficial.

Further soaking in distilled water gives a materially slower cooking product than that given by absolutely untreated dhol and in fact, a sample soaked for 72 hours only yielded 5.76 gm. starch per 100 gm. dhol. This would point to the conclusion that the soaking of the seeds leads to lower the rate of cooking unless in solutions having an alkaline reaction.

In the same way soaking with red earth and N/100 Na_2CO_3 solution yielded a product giving 6.88 gm. of starch per 100 gm. of seeds as against the value of 6.10 when only red earth and distilled water were used.

It may, therefore, be concluded that the treatment with red earth has no merit in inducing a quicker rate of cooking unless the water used is of an alkaline nature. The use of Na_2CO_3 solution for this purpose can therefore be recommended.

Although the treatment with red earth does not improve the cooking qualities of the dhol, yet such a treatment permits the gram to be broken and

husked easier than either untreated gram or soaked grain and at the same time the dholl produced possesses a better colour. From this point of view this peculiar treatment receives justification.

The presence of amylolytic enzymes has been detected both in treated and untreated gram and no doubt the activity of these substances has an important bearing upon the cooking qualities of the products. In the extreme case where the gram was soaked for 72 hours very low cooking values were obtained. In this case the young sprouts were about an inch long and during the preparation of the dholl were broken off and lost. The dholl itself consisted very largely of hollow cotyledons showing that a large proportion of their substance had been transformed and translocated and the low cooking value of the residue is, therefore, no doubt, due to a corresponding increase in the proportion of cellulose and mineral matter.

The conclusions arrived at in this part of the investigation may be summarized as follow :—

1. The fat content of dholl plays a very unimportant part with regard to the rate of cooking.
2. Dholls of different localities have varying rates of cooking.
3. The practice of treating gram with red earth and water has a distinct retarding influence on the rate of cooking when compared with the untreated one, yet this treatment is advantageous in that it allows the gram to be broken and husked easier.
4. The use of hard waters along with red earth retards the rate of cooking of dholl while alkaline waters accelerate it, so that the use of waters which are alkaline in reaction or the addition of sodium carbonate to the water used would be beneficial.

PART III.

THE INFLUENCE OF VARIOUS SALTS ON THE LIQUEFACTION OF STARCH.

In the preceding sections it has been shown that different salts exert varying effects upon the rate of solution of the substance of red gram seeds and that this is accompanied by a similar variation in the rates of solution of the starch and proteid present. It seemed therefore of interest to determine the influence of these salts upon the rate of liquefaction of pure starch.

It is well known that solutions of the caustic alkalies KOH and NaOH convert starch into a paste even in the cold and that acids slowly dissolve it.

Regarding the influence of certain salts on the conversion of starch into paste Payen¹ in 1878 observed that cold saturated or half saturated solutions of KBr or NaBr convert starch into a paste but that other salts such as KCl have no such effect. He further states "starch possesses the property of combining with bases. Upon mixing together a solution of NaOH and water containing starch suspended in it a transparent colourless jelly is formed after a short time which is a compound of NaOH and starch. If this jelly is mixed with a 7% aqueous solution of CaCl_2 a double decomposition takes place and a thick white insoluble mass is formed which is a compound of starch and lime, NaCl being in solution. A series of compounds with starch as basis may be similarly formed."

Later, Asboth² confirmed these observations and Wolff and Fernbach³ showed that carbonates of calcium, magnesium and potassium caused a considerable increase in the viscosity of starch pastes. The latter authors in a still later contribution⁴ on the influence of some mineral substances on the liquefaction of starch state that experiments with starch previously washed until nearly free from calcium and magnesium show that NH_3 , Na_2CO_3 , MgCO_3 and CaCO_3 have about an equal effect whilst Al_2O_3 is without action.

None of these observations, however, throw any light upon the influence of many of the salts found in natural waters upon the rate of liquefaction of starch, and in view of the effect of such substances upon the rate of cooking of dhol it was deemed advisable to make an investigation on the subject.

Rice starch purchased as pure and passed through a 100 mesh sieve was used in these experiments. As it was impossible to make comparisons at a temperature of 100°C . as in the case of dhol, a temperature of 70°C . was adopted after a series of preliminary observations had been made.

All the solutions used except that of CaCO_3 were of N/10 concentration. In the case of CaCO_3 it was added in the solid state to the distilled water in such an amount as would have corresponded to a N/10 strength if it had been actually in a state of solution.

¹ Payen. *Industrial Chemistry*, 1878.

² *Repert. Analyt. Chemie.* 1887, 7, 299.

Compt. Rend. 1905, 140, 1403—1406.

Compt. Rend. 1906, 143, 363—365.

In carrying out these experiments one gramme of starch was added to 50 c.c. of the solution tested and the whole maintained at a temperature of 70°C. in a thermostat for one hour, being constantly stirred the whole time. At the end of this period the liquid was cooled and, if the nature of the solution demanded it, made neutral. 15 c.c. of a malt extract were then added and the saccharification allowed to proceed for two hours at 30°C. The liquid was then made up to 100 c.c. and filtered with kaolin and 50 c.c. of this filtrate was hydrolysed with HCl, cooled, made faintly alkaline with NaOH and the glucose determined with Fehling's solution. After correcting for the amount of reducing material contained in the malt extract, the result was calculated back to starch.

Warth and Darabsett¹ have shown that at 30°C. malt extract does not act on ungelatinised starch and this observation is confirmed by our own experiments. The results may then be taken as representing the amount of starch liquefied under the action of the solution experimented with.

A number of separate series of experiments were carried out, each series being done under uniform conditions and the average of these is as tabulated below :—

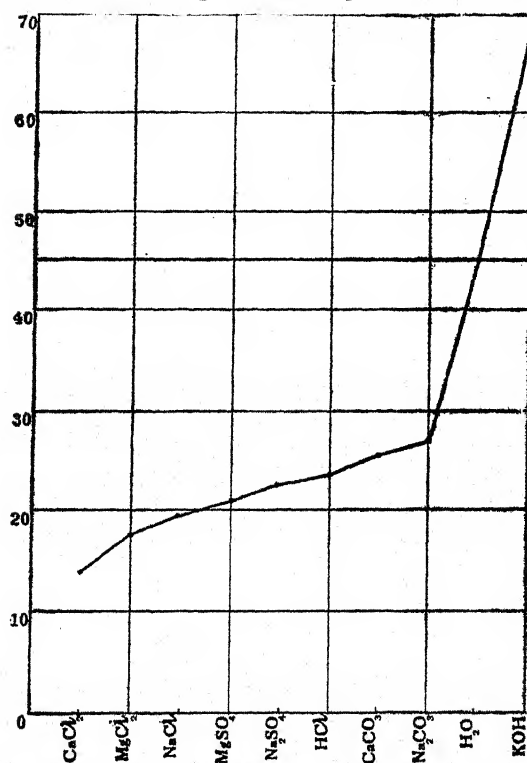
TABLE VI

Showing rate of liquefaction of starch by different N/10 solutions at 70°C.

Solution				% Starch liquefied
Potassium hydrate	...	..	..	67.51
Water	...	...	...	44.91
Sodium carbonate	...	...	...	26.62
Calcium carbonate	...	...	...	25.04
Hydrochloric acid	...	..	..	23.00
Sodium sulphate	...	...	...	22.06
Magnesium sulphate	..	...	...	20.40
Sodium chloride	...	...	...	19.00
Magnesium chloride	...	...	...	17.14
Calcium chloride	...	...	...	13.50

¹ *Memoirs, Dept. Agri. India, Chem. Ser., vol. III, no. 5.*

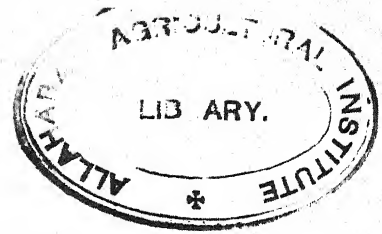
Chart IV. showing relative liquefaction of Starch



The results are plotted out on Chart No. IV, where it will be seen that with the exception of KOH all the compounds experimented with give lower rates of liquefaction than distilled water. Na_2SO_4 and Na_2CO_3 which were found to accelerate the rate of cooking of dholi show a retardation with regard to the rate of liquefaction of starch and this fact strengthens considerably the conclusion previously advanced, that the effect of dissolved substances on the rate of solution of the proteid in dholi is the determining factor affecting the rate of cooking. Attention, too, has been already drawn to the fact that those substances which are used as precipitants for many proteids are exactly those which reduce the rate of cooking.

COIMBATORE,

November, 1915.



P R E F A C E.

THE subject of this Memoir was first taken up in 1911 with the object of providing a cheap and efficient method of preserving seed wheat in small stores against damage by "weevils." These stores were to be small and cheap enough to be suitable for the larger landowners or large enough for village communities. They were also required to be sufficiently simple in construction and in method of working to be suitable for the ordinary Punjab village and its inhabitants.

The preservation of the grain while mainly undertaken with the object of securing sound seed wheat must also leave it fit for human consumption since the needs of the owner might at any time drive him to sell his grain.

These restrictions narrow the possibilities very considerably and put out of court practically all the insecticides and chemical deterrents known.

I therefore turned to the use of carbon dioxide and cheap bins of mud, lined with galvanised iron sheeting to protect the contents against rats or other vermin likely to gain access to an ordinary building of mud or brick, and with the joints soldered to render them gas-tight so that the bin could be filled with the gas carbon dioxide to asphyxiate the insects present in the grain and in the bin.

Bins fulfilling these conditions were erected on the Lyallpur Farm and the experiments described in Chapter II made. These experiments include a series of necessary subsidiary investigations to obtain the required information on conditions of germination, the effect of the gas carbon dioxide, and the moisture contents of wheat as it is found in the Punjab markets, etc. Before the end

of 1912 the variations in the results showed that the entomological information available was insufficient and that we were working in the dark as to the types of insects causing the damage. The entomological staff at the Agricultural College, Lyallpur, was unable to cope with the problem and I consequently asked the then Agricultural Adviser to the Government of India (Mr. J. Mackenna) in March 1913 to post Mr. A. J. Grove, Supernumerary Entomologist, to Lyallpur to take up this side of the work. The matter was officially represented by the Punjab Government in 1913, and early in 1914 Mr. Grove joined the Punjab Agricultural Department on deputation. By this time the problem had broadened itself to include the storing of wheat in large granaries or elevators, and when Mr. Grove arrived our principal object was to secure information which would enable us to deal satisfactorily with grain in large bulk.

On joining at Lyallpur Mr. Grove at once took up the study of the life-histories of the three insects which his tours in the two preceding years had shown to be the ones causing most damage in stored wheat in the Province, and simultaneously with this I extended my investigations on the effect of carbon dioxide and other gases on specimens of the insects isolated by him.

These experiments are described in Chapters III and IV, and Mr. Grove's work on the life-histories of the insects in Chapter I and "the effect of moist and dry atmospheres" in Chapter V.

The division of the work has left Mr. Grove responsible for all the entomological investigations mentioned in the Memoir and included in Chapters I and V and the naphthalene experiments at Gurdaspur mentioned in Chapter VI, all of which are by his pen.

The chemical and physical studies mentioned elsewhere in the note and the mechanical remedial measures are the work of myself, my assistant Bh. Jagat Singh, M.Sc., Assistant Professor of Chemistry in the Lyallpur Agricultural College, and other members of the chemical staff. The entire work has been done in the closest collaboration and all recommendations are made jointly.

The Memoir is a report to the Punjab Government on the "wheat weevil" problem. It has been carried out (for the most part) in the Government laboratories at Lyallpur, and I wish to gratefully acknowledge the Government grants without which the work herein recorded could not have been done. These grants were included in the budget of the Agricultural College, Lyallpur, for the years 1911-1914.

J. H. BARNES.

LYALLPUR, }
July, 1915. }

Mr. A. J. Grove having joined the Mesopotamia field force, he has been unable to correct the second proof of that portion of the Memoir for which he is responsible (*see above*), and Mr. T. Bainbrigge Fletcher, Imperial Entomologist, has very kindly read the final proofs of the entomological chapters for us.

J. H. BARNES.

October, 1916.

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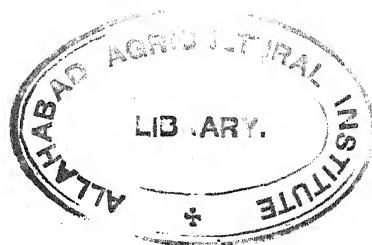
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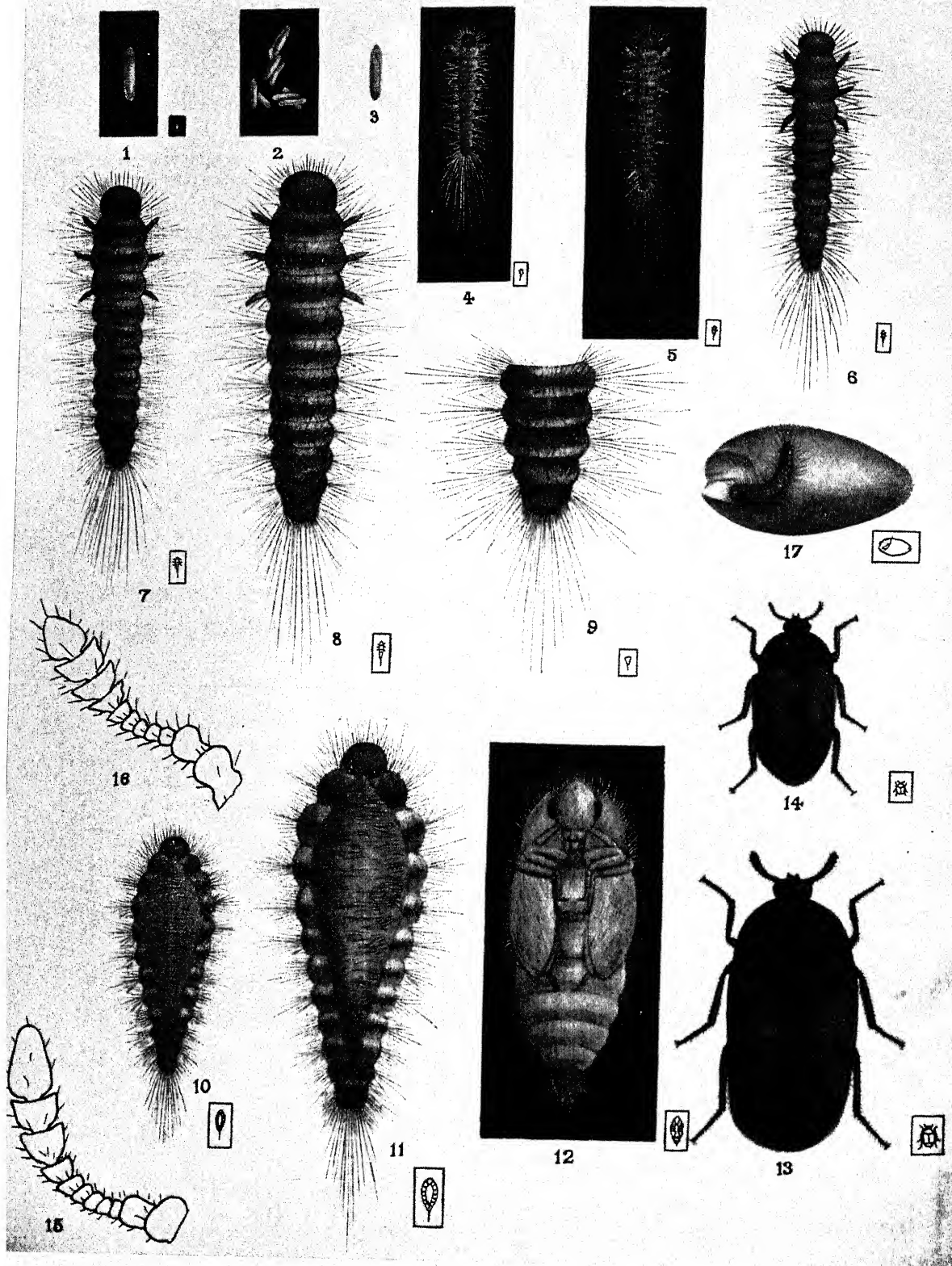
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ATTAGENUS UNDULATUS.

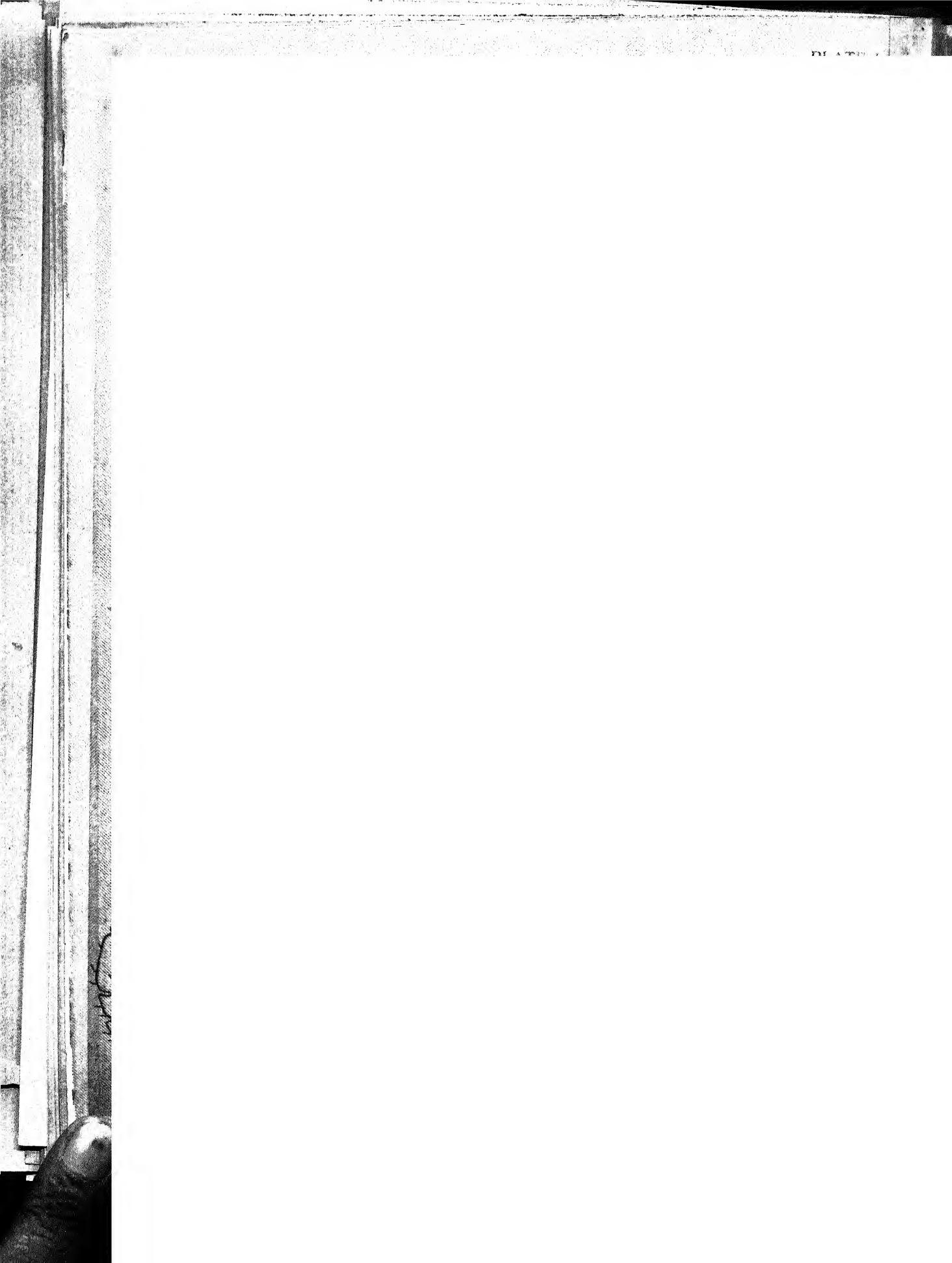
DESCRIPTION OF THE PLATE.

Attagenus undulatus Motsch.

(Frontispiece.)

- Fig. 1. The egg ($\times 13$).
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- „ 15. Antenna of male beetle.
- „ 16. Antenna of female beetle.
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The small figures by the side of the larger ones indicate the natural size of the insects.



THE INSECTS ATTACKING STORED WHEAT IN
THE PUNJAB, AND THE METHODS OF
COMBATING THEM, INCLUDING A
CHAPTER ON THE CHEMISTRY
OF RESPIRATION.

BY

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CHAPTER I.

ENTOMOLOGICAL.

THE study of the insects which damage stored products, and particularly wheat, has not hitherto received from economic entomologists in India the attention merited by the amount of damage and loss for which such insects are responsible. This chapter contains a record of the observations carried out upon the insects found in stored wheat in the Punjab. The work was carried out at Lyallpur, so that the results obtained will refer more especially to that place, and although these results would be applicable to most places in the Punjab, yet the investigations show that in all probability the insects would behave rather differently in other parts of the Province. This variation, as will be shown later will refer mainly to differences of climatic conditions and more especially to humidity.

THE INSECTS WHICH ARE FOUND IN STORED WHEAT
IN THE PUNJAB.

A systematic examination of wheat stores in the Province revealed the following insects as occurring commonly :—

Coleoptera.

Læmophlæus sp. (Cucujidæ).

Attagenus undulatus, Motsch. (Dermestidæ).

Rhizopertha dominica, Fb. (Bostrychidæ).

Tribolium castaneum, Hbst. (Tenebrionidæ).

Latheticus oryzae, Waterh. (Tenebrionidæ).

Alphitobius piceus, Ol. (Tenebrionidæ).

Calandra oryzae, Linn. (Curculionidæ).

Calandra granaria, Linn.¹ (Curculionidæ).

Lepidoptera.

Sitotroga cerealella, Oliv.

From this list it will be seen that the insects are mainly beetles. All of them are small, and to the untrained eye so very much alike, that the native grain dealers and zemindars are unable to separate them from one another, with one or two exceptions, in which cases vernacular names have been given to the insects. For instance the larvæ of *A. undulatus* which are different from those of most other insects found in stored wheat have been named *khapra*, but when they were shown the adult beetle the grain dealers could not distinguish it from other beetles such as *C. oryzae*, *R. dominica* and *T. castaneum*, all of which are given the name *susri*. In fact the zemindars and grain merchants recognize only two kinds of insects attacking wheat, viz., *khapra* and *susri*. In one or two cases, however, it was found that two kinds of *susri* were distinguished, *C. oryzae* being differentiated from the other beetles and designated the *sund wali susri* (the insect with a trunk like an elephant) from the snout resembling an elephant's trunk.

The next problem to be solved was to determine which of these insects were of importance.

Læmophlæus sp. In examining wheat stores this insect was only found in quantity when the wheat had been badly attacked by other insects. Its occurrence was not so common as that of the other beetles, and from general observations it did not seem to be of any great importance. Experiments in the laboratory on the lines carried out with *T. castaneum* recorded later

¹ This insect was only found in two localities and is much rarer than *C. oryzae*.

showed that this insect does not attack sound grain but lives on grains damaged by other insects or in the floury frass produced by them. It is nearly always found in conjunction with *T. castaneum*.

Attagenus undulatus. Practically no information regarding this insect is available. One author¹ merely records its occurrence and another² suggests that in all probability this insect lives on other insects. Investigation showed, however, that in the larval stage the insect attacks wheat grains (see p. 182). It is found practically everywhere in the Punjab, and is in fact an important pest of stored wheat in this province.

Rhizopertha dominica. This is a fairly well-known insect, and it attacks and damages wheat in both the larval and adult stages. It is found in most places in the Punjab.

Tribolium castaneum. This insect which Lefroy has called the Red grain beetle, occurs practically wherever wheat is stored, but, as the following experiment shows, it is not really an active agent in damaging sound grain. On July 23, 1914, four small glass dishes were taken, containing the following :—

- (a) Whole grains of wheat.
- (b) Grains of wheat which had been damaged by other insects, but in which there were no insects present.
- (c) Grains of wheat, some of which had had a portion cut off from the embryo end, some from the apex and some split longitudinally.
- (d) Ground wheat.

Into each of these, 20 active beetles were placed. It had been previously determined that *T. castaneum* would breed well in ground wheat so that (d) would act as a control to the other three. The insects were left undisturbed until August 27th, when it was found that in—

(a) all the beetles were dead ; the grain had been attacked a little where the pericarp was broken and no live larvæ were present. One or two eggs had been noticed but the larvæ from them had died ;

(b) 14 beetles were alive, 5 dead ; eggs and larvæ were present and much frass had been produced, the damaged grain having been practically eaten away ;

(c) 6 beetles were alive, 13 dead, and several dead larvæ were present : much frass had been produced, and all the cut surfaces had been attacked almost equally. The larvæ had evidently passed through several moults as many cast skins were found, but they had evidently died eventually ;

¹ Cotes, E. C. Notes on *A. undulatus*. *Indian Museum Notes*, Vol. III, 1894, pp. 23 and 119.

² Lefroy, H. M. *Indian Insect Pests* (1906).

„ „ *Indian Insect Life* (1909).

(d) 55 beetles were alive, 2 dead, and a large number of larvæ. The surface of the wheat was covered with cast larval skins.

From this experiment it will be seen that the ideal food for *T. castaneum* is ground wheat or flour ; that it cannot live on whole grains of wheat, but can live on grains which have been damaged by other insects or mechanically ; and in fact it may be said that this insect is not a grain beetle but a flour beetle.

Latheticus oryzæ. There is not much information available regarding the occurrence of this insect in India. Lefroy¹ (1909) does not mention it, and Fletcher² (1914) merely records it in a list of insects attacking stored products. It is very closely allied to *T. castaneum* and very similar to it, and this may account for its not having been recorded. It does not occur as commonly as *T. castaneum* but has been found at Lyallpur, Ludhiana, Jagraon, Sargodha, Sangla Hill and Jaranwala. The insect was tested in exactly the same way as *T. castaneum* with the same results.

Alphitobius piceus. This beetle was only found in wheat which had become damp or which had been badly damaged. It was nearly always found associated with attack by white ants. It is a large black beetle and the larva is a whitish yellow grub with a darker coloured head. All attempts to rear it on wheat in any form failed ; probably it is merely a scavenger and does not attack the grain.

Calandra oryzæ. This insect is perhaps the best known of all the insects attacking stored wheat in India and is a pest of great importance, the insect attacking the wheat in both larval and adult stages. It is found in most parts of the Province.

Calandra granaria. Little is known of the occurrence of this insect in India. Lefroy¹ (1909) and Fletcher² (1914) mention it, but no account of it is given. The writer (A. J. G.) has recorded it in two places : Rewari (2 specimens), and Gurdaspur (a few specimens mixed with *C. oryzæ*) ; but it is not nearly as common as *C. oryzæ* nor of such importance.

Sitotroga cerealella. This small grain moth was only found in any numbers in the Gurdaspur district, and though it probably occurs in other places, it was not observed, and the grain dealers were apparently not familiar with it, so that except in the Gurdaspur district it is probably not of much importance. The larvæ damage the grain (see pp. 203 and 204).

It will be seen, therefore, from what has been recorded above, that only three of the insects found in the stored wheat are actively responsible for damage to the wheat, viz., *A. undulatus*, *R. dominica* and *C. oryzæ*.

¹ Loc. cit.

² Fletcher, T. Bainbrigge. *South Indian Insects*, 1914, Government Press, Madras.

DISTRIBUTION.

Having determined which insects are responsible for the destruction of the wheat, the next point to be considered is the distribution of the various insects in order to throw some light upon their relative importance in the various places in the Punjab. In August and September 1913 a short tour was made to some of the chief wheat centres in the province, Ludhiana, Moga, Ferozepur and Lyallpur being visited. At this time very little was known of the insects attacking wheat in the province with the possible exception of *C. oryzae*, and the visit was of the nature of a preliminary examination to determine what insects were to be found in the wheat. In August 1914 a more comprehensive inspection of the chief markets of the province was made, and in addition to the examination of the wheat stores in the market or *mandi* itself, wherever possible, one or two of the villages in the vicinity from which the *mandi* received its supplies, were also examined. The results of these observations have been tabulated below :—

TABLE I.

Name of place	<i>A. undulatus</i>	<i>R. dominica</i>	<i>C. oryzae</i>	REMARKS
LYALLPUR.				
Lyallpur Mandi ...	ccc*	cc	c	Average rainfall 12·66 inches. Subsoil water 50—80 feet below the surface. Cultivation only possible where canal irrigation water available. Atmosphere generally speaking dry, but irrigation has raised the humidity.
Chak No. 65 ...	cc	cc	f	
Kamalpur ...	c	c	...	
Chak No. 36 ...	c	c	...	
Panjwar ...	...	c	...
Chukera ...	...	c	...
GURDASPUR.				
Gurdaspur Farm	ccc	Average rainfall 34·02 inches. Subsoil water very near surface. Conditions moist.
Nawanpind ...	...	c	c
Bābi ..	...	f	f
Mustafabad ...	f	...	c	

* N.B.—In the table the following signs have been used :—

ccc	indicates that the insect is very common.
cc	ditto common.
c	ditto fairly common.
f	ditto found, but in small numbers.

TABLE I.—*continued.*

Name of place	<i>A. undulatus</i>	<i>R. dominica</i>	<i>C. oryzae</i>	REMARKS
AMRITSAR.				
Amritsar Mandi ...	cc*	c	c	Average rainfall 23.98 inches. Subsoil water 10 to 20 feet below surface. Moist.
Sultanwind ...	...	...	ccc	
Kot Said Mohd ...	cc	f	f	
JULLUNDUR.				
Jullundur Mandi...	cc	f	c	Average rainfall 26.8 inches.
Phagwara Mandi...	c	c	cc	
LUDHIANA.				
Ludhiana Mandi...	c	...	c	Average rainfall 26.23 inches. Subsoil water 20 to 30 feet below surface. Irrigation mainly from wells.
Chapki ...	...	...	c	
Jagraon Mandi ...	c	c	c	
Moga ...	cc	f	...	
SIRSA.				
Sirsa Mandi ..	ccc	...	...	Rainfall about 16 inches. Conditions very dry.
Buraguda ...	cc	...	...
Khaipur ...	ccc	...	...
REWARI.				
Rewari Mandi ...	f	...	f	Rainfall about 25 inches. Conditions dry.
Rampura ...	f	...	...
Gokalgarh ...	c	...	...

* N.B.—In the table the following signs have been used :—

ccc indicates that the insect is very common.

cc ditto common.

c ditto fairly common.

f ditto found, but in small numbers.

From the table, it will be seen that although generally speaking all three insects are found all over the Punjab, yet in some districts they are not of equal importance, whereas in others all three seem to be of almost equal importance. For instance, in districts such as Lyallpur, Moga, and Sirsa *A. undulatus* seems to be the commonest insect, whereas in the Amritsar and Gurdaspur districts *C. oryzae* is the greatest source of loss. *R. dominica* seems to be generally troublesome. In the districts of Jullundur, Ludhiana, Jagraon, and Phagwara all three appear to be of almost equal importance.

In considering these results it must always be remembered that they were obtained upon a single visit and examination, but in each case the actual observations were supplemented by information obtained from grain dealers and merchants living in the place, many of whom had had lengthy experience of stored grain. The results are also supported by experiments connected with the effect of dryness and moistness on these three insects, but it is not proposed to discuss this point here as it will be dealt with in another place (see p. 261 *et seq.*).

In order further to supplement these results samples of insects found in wheat were obtained from a number of other places in the Punjab. This was done through the kindness of Mr. P. MacBrien of Messrs. Sanday Patrick & Co.; Mr. A. J. Peake of Messrs. Clements Robson & Co.; and Mr. Fritz Gidion of Messrs. Louis Dreyfus & Co., the representatives of these wheat exporting firms at Lyallpur. Tubes were sent to the sub-agencies of these firms in different places and the insects obtained placed in them and returned to Lyallpur for identification.

The record in tabular form is as follows :—

TABLE II.

Name of place	Collector	<i>A. undulatus</i>	<i>R. dominica</i>	<i>C. oryzae</i>
Lyallpur ...	L. D.*	+	+	+
...	S. P.	+	+	+
Chak Jhumra ...	C. R.	+	+	-
Sangla Hill ...	S. P.	+	+	-
...	C. R.	+	-	-
...	L. D.	+	+	-
...	L. D.	+	+	+
Gojra ...	S. P.	+	-	+
Toba Tek Singh ...	S. P.	+	+	+
...	C. R.	+	+	-
Sargodha ...	S. P.	+	+	-
Sillanwali ...	S. P.	+	+	-
Bhalwal ...	S. P.	+	+	-
Nankana Sahib ...	S. P.	+	+	+
Jaranwala ...	S. P.	+	+	+
...	C. R.	+	-	-
Tandlianwala ...	S. P.	+	+	-
Sukheki ...	S. P.	+	+	+
Patti ...	S. P.	+	+	+
Jhang ...	S. P.	+	-	-
Okara ...	S. P.	+	+	-
Phagwara ...	S. P.	+	-	+
Kasur ...	S. P.	+	+	+
Patokki ...	S. P.	+	+	-
Moga ...	S. P.	+	+	-
Multan ...	L. D.	+	+	+
Sukkur ...	L. D.	+	+	-

* L. D. refers to Messrs. Louis, Dreyfus & Co.

S. P. refers to Messrs. Sanday, Patrick & Co.

C. R. refers to Messrs. Clements Robson & Co.

+ = Present.

- = Absent.

The most noticeable features about this table are the frequency with which *A. undulatus* occurs (specimens being received from every place), and the comparative scarcity of *C. oryzae*. It also points to the conclusion that *A. undulatus* and *R. dominica* have a wider distribution in the province than *C. oryzae*. In considering these results it must however be remembered that they cannot be taken in any way as final, but they are useful in indicating the occurrence of the insects.

THE LIFE-HISTORIES OF THE INSECTS FOUND IN STORED WHEAT.

Before giving the details of the life-histories of the insects dealt with, it will be useful to give some idea of the way in which the observations were carried out. A criticism often applied to entomological investigations is that the results, which have been obtained by observations in the laboratory or insectary, are not always of the value which they should be, owing to the difference which exists between the natural conditions and those under which the observations were made. With this investigation, however, the difference between the natural conditions and the laboratory conditions is not so very marked with the possible exception that the diurnal variation in temperature in a *kotha* or large bin of stored wheat would not be as great as that of the laboratory. This was compensated for by keeping the insects in a closed chamber (an incubator with a water jacket was used but no artificial heat of any kind was employed) so that the temperature would not vary as much as the laboratory itself during the day but the seasonal variation would still be operative. The chamber served another purpose in protecting the insects under observation from accident, and also from the frequent dust storms which are such a nuisance during the hot weather in the Punjab. The insects under observation were isolated in small porcelain crucibles such as are in common use in chemical laboratories, and each was examined daily and notes recorded. In describing the life-histories of the insects, the three which, as has been shown above, are the most important agents in causing damage to the wheat will be taken first and the other insects of lesser importance later.

Attagenus undulatus, Motsch. (Frontispiece).

Although this insect is so common in the Punjab, and of such importance as a pest of stored wheat, that it has attracted the attention even of the native grain dealers in that they have given it a distinctive name in the vernacular, viz., *khapra*, yet it has received little notice from scientific entomologists.

It is first mentioned in Indian entomological literature as a pest by Cotes (1894) in Indian Museum Notes. In these (Vol. III, No. 3, page 119) in which figures of the larva and the beetle are given, it is stated:—"It is known as 'khapra' in the Delhi bazaar, where it is said sometimes to destroy as much as six or seven per cent. of wheat stored in godowns." Lefroy (1906) mentions the insect in Indian Insect Pests though apparently he does not attach any importance to it as a grain pest but says:—"A dermestid (*Æthriostoma undulata*) closely allied to the last is reported from India in wheat. This or the last is the insect found in grain in Gujerat where it is believed to be of use in checking other grain insects notably the Red grain beetle. This belief is so firmly held that the dermestid is introduced in the grain infected with insects as a check on them." The same author (1909) again records the insect making much the same comment "*Æthriostoma undulata* (Motsch) is found in wheat. Its larva is broad, with short hairs, with no anal tube or hooks. The part it plays in wheat is not ascertained but it is likely to be predaceous upon the other insects there or to feed on their dead bodies."

Investigation has shown that this insect certainly does not play the rôle suggested by Lefroy in his later note, but is a very active agent in damaging the wheat.

A. undulatus is also included by Fletcher¹ (1914) in a list of insect pests of stored products, but no account of it is given as its occurrence has not been definitely noted in Southern India.

The egg (Frontispiece, figures 1-3). The eggs are laid loose among the grains of wheat, and as a rule singly. Sometimes they have been observed to be laid in the groove on the grain and in this case two or three may be laid together. The size and shape of the eggs vary to some extent but a typical egg is narrow, cylindrical, rounded at one end and somewhat pointed at the other; the pointed end having a few hairs upon it. In colour it is a translucent white when laid, and remains so for some time. The surface of the egg-case is smooth. After a while, as development proceeds, reddish, or yellowish brown markings appear from which the form of the developing larvæ can be distinguished. The markings take the form of transverse brown bands, and a brown spot at the rounded end, and are due to the long brown hairs with which the segments of the larvæ are furnished, the spot at the end of the egg marking the long tail hairs which lie coiled up inside the shell.

Compared with other insects which attack stored wheat, *A. undulatus* lays a small number of eggs. The largest number observed was 41 and as

¹ *Loc. cit.*

a general rule each female lays between 35 and 40 eggs. The eggs are not laid with any regularity and generally the female lays a large number the day after fertilization (as many as 20 having been recorded) and then a few each day for the remaining days of its life.

Below, two tables are given showing the number of eggs laid each day by two females :—

TABLE III.

Dates of observations				Number of eggs found	
May 2-May 3, 1914	14
May 3-May 4, 1914	3
May 4-May 5, 1914	6
May 5-May 6, 1914	7
May 6-May 7, 1914	7
May 7-May 8, 1914	0 (dead)
TOTAL				...	37

TABLE IV.

Dates of observations				Number of eggs found	
Sept. 2-Sept. 4, 1914	2
Sept. 4-Sept. 5, 1914	19
Sept. 5-Sept. 6, 1914	16
Sept. 6-Sept. 7, 1914	0
Sept. 7-Sept. 8, 1914	1
Sept. 8-Sept. 9, 1914	0 (dead)
TOTAL				...	38

The hatching of the egg. The larva emerges from the egg by breaking through the shell at the pointed end and crawling through the aperture thus formed. After the body is free from the shell, the larva often remains for some time with the long tail hairs still inside the shell and then finally releases itself and crawls away. The aperture in the egg-case does not close after the larva has emerged, and the shell itself becomes thrown into a number of close longitudinal wrinkles which give the empty egg-cases a beautiful iridescent appearance.

The period which is occupied between oviposition and the hatching of the egg varies, of course, according to the season of the year, but the variation is not extensive. When the insect is most active, that is, during the hot months, the period is five days. The following table will give an idea of the time taken at different times in the year, during which adult females are found. From October to March the insect remains in a hibernating condition in the larval stage, so that during these months no eggs are produced.

TABLE V.

Date of oviposition			Date of hatching			Period
1914			1914			
11th April	...	...	17th April	...	...	7 Days.
3rd May	...	...	8th May	...	...	6 "
15th "	...	...	19th "	...	...	5 "
12th June	...	...	16th June	..	...	5 "
25th "	...	...	30th "	...	...	6 "
13th July	...	...	18th July	...	...	6 "
31st "	...	...	5th Aug.	...	...	6 "
31st Aug.	...	...	5th Sept.	...	...	6 "
10th Sept.	...	...	15th "	...	...	6 "

The larva. The freshly hatched larva (Frontis. figure 4) is of a uniform yellowish white with the exception of the head which has a brownish or yellowish brown tinge and the hairs on the segments which are yellowish brown. In a short time the colouration of the body becomes evident and consists, in addition to the darkening of the colouring of the hairs and head, of transverse bands of a yellowish brown colour on the segments. The underside of the larva is of a uniform cream colour. The segments are furnished with two kinds of hairs, long simple hairs, and short barbed ones. The long hairs are arranged in groups and project from either side of the segments. The barbed ones are found scattered all over the dorsal surface of the body, but particularly congregated into groups on the posterior margins of the terminal segments. In this (the first instar), the long hairs are very long in proportion to the size of the body and the barbed hairs are comparatively few in number and are only arranged in a group or fringe on the ultimate and penultimate segments. As the larva develops the long hairs become relatively shorter in proportion to the body and the number of barbed hairs increases. In the wheat, these barbed hairs are often found felted together in irregularly shaped brown masses, especially when the wheat has been infected with the larvæ for some time.

The young larva moves about actively in search of food and crawls upon the grains in search of a suitable place to attack. After a period of continuous feeding the larva becomes darker in colour and finally leaves the spot where it was feeding and crawls away to hide itself preparatory to moulting. The larvæ kept under observation invariably crept between the underside of the wheat grains and the bottom of the crucible. In

moulting, the skin splits along the back from the head to the region of the penultimate segment, and the larva crawls out leaving the cast skin behind and then immediately recommences to feed.

In the second instar (Frontis. figure 5) very little difference is noticeable beyond the increase in size. The general colour is a little darker and the number of hairs in the fringes on the terminal segments is greater, giving these a darker brown appearance. These fringes are however still found only on the last two segments.

In the third instar (Frontis. figure 6), again there is merely a general darkening in colour and increase in the number of the barbed hairs in the fringes at the end of the body. The long hairs also have now become reddish brown in colour rather than yellowish brown.

In the fourth instar (Frontis. figure 7) a little more change is noticeable. The body and head are of a general brown colour, except the folds of integument between the segments which still retain the yellowish tinge, and when the larva is extended give it a banded appearance. The most noticeable difference however is that a fringe of barbed hairs has now appeared on the third segment from the end.

- In the fifth instar (Frontis. figure 8) a further change has taken place. A fringe of barbed hairs has now appeared on the fourth segment from the tail end. Beyond this and the increase in size this stage closely resembles the previous one.

In the succeeding instars these fringes of barbed hairs do not extend any further up the body but the number of hairs in each is increased with each moult, giving the terminal segments a very dark appearance. In the case of a larva, which had moulted ten times (December, 1914), these hairs had assumed the form of thick brushes increasing in density from the fourth terminal segment to the tail. The appearance and colour of the hinder end of the body is therefore an indication of the age of the larva.

The number of times that the insect casts its skin varies according to the season, and also according to the sex of the resulting adult. In fact no definite number can be stated as the typical number of instars for any particular time of the year, for considerable variation may occur even among the progeny of the same parent. It is difficult to see what conditions control the number of moults, for all the insects kept under observation were reared under what appeared to be identical conditions in every respect and yet variation even among the progeny of the same parents would occur. For example, of two

larvæ hatched from eggs laid on the same day (19th May 1914) by the same female, one passed through seven moults, pupating on June 22nd, and the other through four moults pupating on June 8th. It is true that in this case the resulting adults were of different sexes, the former being a female and the latter a male, and as a general rule the female-producing larvæ pass through one more moult than the male-producing ones, yet it is interesting from the biological point of view that two eggs from the same female, reared under the same conditions, should give such different results. As has been said above, the season of the year is also a factor in determining the number of moults. During the hot dry months of May, June and part of July the insects developed very rapidly and the number of moults was reduced, the smallest number observed being four. The general number during the period was six for the females and five for the males. After the advent of the rains the number of moults increased and development was considerably prolonged. Here again considerable variation was observed. When the insect is active the interval between the moults is generally about five days. Later on in the year, after the rains have fallen, the period becomes gradually more extended until the larva passes into a state of hibernation when the period becomes very extended indeed, often to as much as five months. On the next page are given a few examples illustrating the variation in the number of moults passed through by different insects:—

TABLE VI.

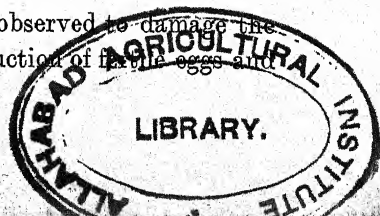
Sex of adult	Date of hatching	Date of first moult	Date of second moult	Date of third moult	Date of fourth moult	Date of fifth moult	Date of sixth moult	Date of seventh moult	Date of eighth moult	Date of ninth moult	Date of tenth moult	Date of eleventh moult	Date of twelfth moult	REMARKS
♂	1914 Apr. 17	1914 Apr. 25	1914 May 1	1914 May 6	1914 May 13	1914 May 16	1914 May 23	1914 May 31	1914 June 3	1914	1914	1915	1915	Eggs obtained from the same female and laid on the same day.
♂	May 19	May 23	" 30	June 3	June 8									
♀	" 19	" 23	" 27	May 31	" 3	June 9	June 18	June 22						Ditto.
♂	June 4	June 9	June 13	June 16	" 20	" 25								
♀	" 4	" 9	" 12	" 16	" 20	" 25	July 1							Ditto.
♂	July 11	July 15	July 18	July 22	July 27	Aug. 2								
♀	" 18	" 22	" 27	" 31	Aug.	" 12	Aug. 19	Aug. 27	Sept. 6	Sept. 16	Sept. 29	Apr. 3	Apr. 22	Ditto.
♂	Aug. 5	Aug. 12	Aug. 16	Aug. 20	" 24	" 29								
♀	" 5	" 11	" 16	" 20	" 24	" 30	Sept. 5							Ditto.
♂	Sept. 6	Sept. 10	Sept. 15	Sept. 21	Sept. 29	Oct. 19	Apr. 3 1915.	Apr. 24 1915.						

The pupa. In common with other Dermestidæ, the insect pupates enclosed in the last larval skin (Frontis. figures 10 and 11). In the last ecdysis the larval skin splits along the back from just behind the head to the region of the penultimate segment but the skin is not cast off and the dorsum of the pupa protrudes through the aperture formed by the slit. The shape of the skin is distorted somewhat, the thorax of the pupa being much wider than that of the larva, so that the aperture in this region is much wider. The dorsal surface of the pupa seen through this aperture is covered with hairs and the outlines of the portions of the body are not very marked. The hairs along the median line are often arranged to form a distinct ridge, and the colour is of a lighter brown than that of the larva. Seen from the underside, however, all the parts of the future beetle are clearly marked. The general colour of the abdomen is a pale yellowish brown, the wing cases, appendages and head being darker in colour. The eyes are distinctly marked. Figures 10 and 11 (Frontispiece) give an idea of the pupa from the dorsal surface, whilst still enclosed in the larval skin and figure 12 is a drawing of the pupa from the ventral surface, and removed from the larval skin. A noticeable feature about the pupæ is their difference in size, the pupa of the male beetle (figure 10) being markedly smaller than that of the female (figure 11).

When the beetle emerges from the pupa case, this is pushed away to the tail end of the enclosing larval skin, but the beetle still remains enclosed in the larval skin until colouration develops and the insect matures. This may take two or three days.

The adult. *A. undulatus* is a small, active, brownish black beetle, not much longer than it is broad, the head small, compared with the rest of the body and the division between the thorax and abdomen not marked. The colouration in the female is lighter than that of the male. In the male the head and thorax and tip of the abdomen are of a dark brownish black, the elytra and the appendages of a lighter colour. In the female the difference in colour between the head and thorax and the elytra is not so marked. The eyes are black. The whole of the surface of the body and elytra is covered with fine light-coloured hairs, giving the body almost a velvety appearance. A fringe of brown hairs covers the tip of the abdomen. The females are easily distinguished from the males by their larger size, and there is also a difference in the shape of the antennæ in the two sexes. In the male the last joints are more elongated and the basal joints are also different (figures 15 and 16).

The insects in the adult stage have never been observed to damage the wheat. The whole function of this stage is the production of fertile eggs and



when this is accomplished the adults die. The beetles, however, are furnished with well developed mouth-parts so that *a priori* they should feed on something and they have been observed sometimes to gnaw away at the surface of the wheat grains which have already been eroded by the larvæ. Food does not, however, seem to be necessary for the production of eggs, for in several instances fertilized females gave the normal number of eggs without being supplied with any food whatever. The adult beetles live for a short time compared with the larvæ, the longest observed period being ten days.

The females only require to be fertilized once to produce the full number of eggs. During copulation the male remains at the side of the female, the tips of their abdomens approximating. The pair only remain together for a short time, the time in three cases observed varying from one to one-and-a-half minutes. The males are capable of fertilizing more than one female.

The length of life-history. The Dermestidæ are characterized by a great adaptability to circumstances and this insect furnishes a good example of the phenomenon. The most advantageous conditions for its development are found in the hot and dry weather which occurs in the Punjab during the months of May and June and part of July. During these months the insect is very active and the life-history is short, the shortest period observed being twenty-five days for males (8th June to 2nd July) and thirty-three for females (9th June to 11th July). With the advent of the rains, however, the life-history lengthens, being about 30 days for males and 40 for females (July and August). From September onwards the conditions seem to be inhibitive to complete development and the insect remains in the larval stage in a condition of partial or complete hibernation. During September and October the larvæ moult fairly regularly but with lengthened periods between the moults, but from October onwards they remain completely dormant. This goes on until about the beginning of April of the succeeding year when the larvæ again exhibit activity. In the case of the isolated insects kept under observation during this period they remained between the under surface of the wheat grains and the bottom of the containing crucible. It was noticed, however, in the case of a large number of larvæ which were kept in a vessel with a quantity of wheat, that they forced their way down among the grains clustering together as if for warmth, whereas, when active, they are mostly to be found on the surface of the wheat. Under natural conditions the larvæ have been found in various places during the hibernating period. Where the wheat has been stored in godowns or *kothas* (native storehouses) the larvæ are almost invariably to be found in the cracks and crevices between the bricks or in the plaster on

the walls. In one instance over a hundred larvæ were extracted from a crack, roughly an inch and-a-half long and an inch deep, in the plaster on the wall of a *kotha* and as the walls were full of such cracks and each one seemed to contain larvæ, this will give some idea of the number of larvæ which were hibernating in the place. Where the wheat is stored in gunny bags the larvæ often remain in the bags among the wheat.

It will be seen, therefore, that this insect when it meets adverse conditions merely passes into the dormant state, and continues so until conditions change. It follows, from this habit of hibernating in the larval stage, that from October to April no increase in the numbers of the insects occurs, as during this period no adults are to be found. Below is given a number of examples of the period of life-history of the insect at different times during the year. For the sake of convenience the table commences with the month of April as it is at the beginning of this month that activity commences :—

TABLE VII.

Date of oviposition	Date of emergence of adult	Sex	Period
1914	1914		
11th April ...	6th June ...	♂	57 Days.
15th May ...	25th „ ...	♀	42 „
15th „ ...	12th „ ...	♂	29 „
8th June ...	2nd July ...	♂	25 „
9th „ ...	11th „ ...	♀	33 „
13th July ...	24th Aug. ...	♀	43 „
16th „ ...	17th „ ...	♂	23 „
31st Aug. ...	29th April 1915 ...	♀	242 „
10th Sept. ...	30th „ „ ...	♂	233 „

The number of generations. For this purpose it will be as well to consider the year as beginning with April and ending with the following March, for eggs are not usually available until the middle or end of April. This being so, it may be said that there are four generations in the year, the first three, which occur during the period of greatest activity, being the shortest. The fourth has a very extended period as it occurs during the period of hibernation, and extends from September until the following April or May. In the example given, the first generation is considered as commencing in the beginning of May.

In obtaining these results the periods given are necessarily those of the females but in many cases the males matured in a much shorter time.

TABLE VIII.

Number of generation	Date of oviposition	Date of emergence	Period
	1914	1914	
First ...	13th May	19th June	38 Days.
Second ...	22nd June	26th July	35 "
Third ...	31st July	7th Sept.	39 "
Fourth ...	10th Sept.	30th April 1915	233 "

The effect on the grain. The larvæ of *A. undulatus* attack the grain in a characteristic way. Passing, as they do, the greater part of their life outside the grains, the damage that they cause takes the form of a gnawing away or erosion of various parts of the grain. No particular part of the grain seems to be especially attacked, but it has been determined by experiment that the attack always begins at some weak place in the pericarp. It was observed occasionally that larvæ bored their way into the grains at the place where the primary attack was made, but on the other hand other larvæ merely gnawed away at the exposed surfaces of the grain, and a wheat dealer at Ludhiana informed the writer that he had noticed that wheat attacked by this insect was often white due to the fact that the larvæ had gnawed away the yellow pericarp.

During the investigation it was considered necessary to determine whether the larvæ in their varying stages could attack whole grains of wheat. Accordingly a quantity of larvæ was reared on grains which were already damaged. Then a number of larvæ in each of the first to the fifth instars was isolated with whole grains of wheat which were carefully examined to see that the pericarp was intact. It was found that in the first, second and third instars the larvæ were unable to penetrate into entire grains but in the fourth instar, that is after the third moult, they could do so. In practice, however, this fact would not have very much significance except perhaps in the primary attack, but even then there would be enough damaged grains for the freshly-hatched larvæ to penetrate. Moreover, the primary attack is in all probability made by larvæ which have passed the third instar and have been hibernating through the cold weather and the grains which they might damage would provide sufficient food for the early stages of the succeeding generation.

Another interesting feature of its method of attack is the prevalence of the insect at the top of the wheat. It certainly can and does penetrate to

some depth into the wheat, but the greatest amount of damage always occurs in the first six to twelve inches, and during the first year. The damage caused by the insect very soon becomes obvious owing to the collection of cast larval skins seen lying about the surface of the grain, and when the attack becomes bad, the quantity of these skins and other detritus which collects on the surface of the wheat is extraordinary.

The larvæ of *A. undulatus* unlike the adults of *R. dominica* and *C. oryzae* consume all the material they gnaw from the grains, and wheat attacked by this insect does not become mixed with the floury matter which characterizes the attack of the other two insects. A quantity of dust and frass is produced but this consists almost entirely of the excrement, which is composed of small white or yellowish white pellets. This is quite characteristic and often indicates the cause of the damage to the wheat when no insects are to be found.

Although the normal food of the larvæ is the wheat grains, yet they can live on flour or the floury matter which is often found amongst wheat, and several larvæ have been reared on this material. This may possibly be resorted to by the young larvæ when they are unable to find grains which are suitable for them to attack.

Another curious fact regarding this insect is that wheat which is badly attacked by it, always feels hot to the touch, and it was found that the temperature of a number of larvæ collected together was considerably above the air temperature.

Rhizopertha dominica, Fb.

Like *A. undulatus* this insect has not received much attention in India but in America its importance as a pest of stored grain has been recognized, and an account of it was given by Chittenden¹ (1911). It has also been recorded by other observers in other countries. This author (Chittenden) gives a short bibliography. In the literature on Indian economic entomology it has not received much attention. Records of the occurrence of the insect were given at different times in Indian Museum Notes by Cotes² (1889-1894). Stebbing³ (1903) also gives a short description of the insect and a few notes

¹ Chittenden, F. A. The Lesser Grain Borer (*R. dominica*), *Bull., U. S. Dept. Agri. Bureau of Entomology*, 96, Part III, pp. 29—47, figs. 7 and 8.

² Cotes, E. C. Notes on *R. dominica*. *Indian Museum Notes*, Vol. I, 1889, p. 60.

" " " " " Vol. II, 1889, p. 27.

" " " " " Vol. II, 1893, p. 150.

" " " " " Vol. III, 1894, p. 124.

³ Stebbing. Note on *R. dominica*, *Indian Museum Notes*, Vol. VI, pp. 25 and 26.

on its life-history. Lefroy (1906) does not mention it in Indian Insect Pests and merely mentions it as a household pest in Indian Insect Life (1909). Fletcher¹ (1914) records it as a minor pest and gives some details of its life-history. None of these authors, however, gives any complete data of the bionomics of the insect so that information on these points, which are of importance in studying the insect as a pest, had to be worked out afresh.

The egg. (Plate II, figures 1 and 2.) The egg has been described by Chittenden as :—"White, of elongate pear-shaped form, one end forming a rather narrow stem or neck, bearing on one side at its base a transverse impression or suture, causing the egg to bend somewhat to one side. Both ends of the eggs are rounded : the surface is slightly polished and apparently somewhat rough. The length of the egg is 0.6 mm. and across its thickest portion a little over 0.2 mm."

A little variation from this description has been noticed, the eggs when they are freshly laid are perfectly white, but after a short while a pinkish tinge appears particularly towards one end, and this is the characteristic colour of the eggs. The shape too is rather more cylindrical than pear-shaped, and the narrow neck or stem is really a small peduncle formed by a pulling out of the end of the egg-case during the process of oviposition.

Each egg is laid separately and either loose among the grains or in some cases stuck to them. It has also been noticed that the eggs are sometimes laid in clusters and not singly. This nearly always takes place when a large number of eggs is laid on the same day, as often occurs. The process of oviposition was observed in one instance. The ovipositor of a female which had eaten its way right inside a grain of wheat was thrust out through a hole in the grain. The ovipositor became very much elongated, when fully extended being nearly as long as the abdomen, and then became tense and swollen due to the passage of the egg into its lumen. Sometimes the internal pressure was so great that the ovipositor became coiled upon itself. The egg then passed into the posterior portion of the organ and was then rapidly extruded, but the egg was held for some time in the distended orifice and the organ waved about as if seeking for a place in which to deposit the egg. After a short interval the egg was released. The eggs were laid in rapid succession, following one another quickly down the organ.

For its size this insect lays an extraordinary number of eggs and the period during which it is actually ovipositing may be an extended one. The largest number observed is 586 and the general number is between 300 and 400.

¹ *Loc. cit.*

PLATE II.

Rhizopertha dominica.

- Fig. 1. The egg ($\times 20$).
 2. A cluster of eggs ($\times 10$).
 3. A freshly emerged larva, dorsal view ($\times 26$).
 4. A freshly emerged larva, lateral view ($\times 26$).
 5. The larva after the first moult, dorsal view ($\times 26$).
 6. The larva after the first moult, lateral view ($\times 26$).
 7. The larva after the second moult ($\times 26$).
 8. The larva after the third moult ($\times 26$).
 9. The fully developed larva just previous to pupating ($\times 20$).
 10. The pupa. Ventral view ($\times 20$).
 11. The adult showing the attitude when actively moving about ($\times 20$).
 12. The antenna.
 13. A grain showing the larva inside ($\times 6$).
 14. A grain showing the pupa in the cavity excavated by the larva ($\times 6$).
- The small figures observed by the side of the larger ones indicate the natural size of the insects.



1



2



3



4



5



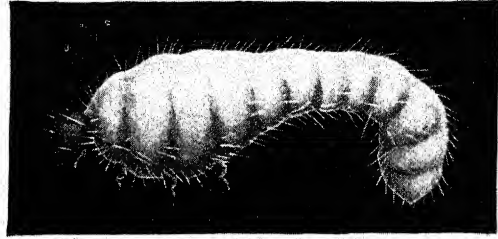
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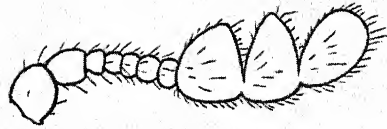
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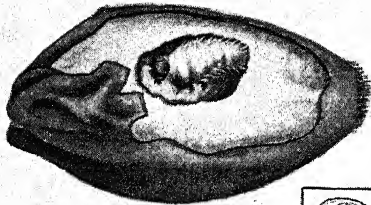
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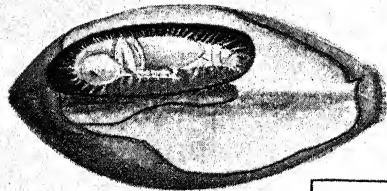
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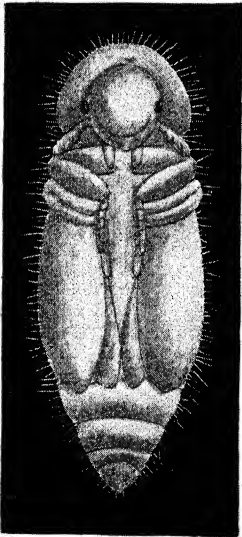
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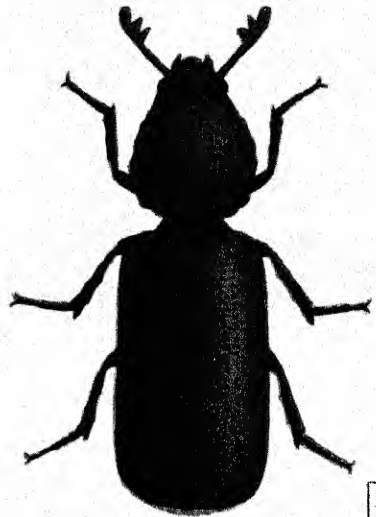
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14



10



11

RHIZOPERTHA DOMINICA.

Below is given the number of eggs laid by several females and the periods during which each insect laid the eggs :—

TABLE IX.

Date of commencement of oviposition	Date of death	Number of eggs laid	REMARKS
1914			
28th May ..	.....	388	Ceased laying on 27th July 1914.
6th June ...	8th August 1914 ...	329	Ceased laying on 22nd July 1914.
9th July ...	23rd April 1915 ...	586	Ceased laying eggs on 18th November 1914.
10th „ ...	7th August 1914 ...	209	Ceased laying on 3rd August 1914.
11th August ...	... ..	480	Still alive on 4th May 1915. 3 eggs laid on 30th April.
22nd „ ...	... ..	381	Still alive on 4th May 1915. Ceased laying on 22nd September.

The time taken to produce this number of eggs is considerable. For instance, one female commenced to lay eggs on 9th July 1914 and continued to do so until 21st August when it ceased laying but still continued to live. Up to this time it had laid 349 eggs. On 4th September it was still alive and another male was placed in the crucible with it and allowed to remain until the 18th when it was removed and it was found that the female had laid 9 eggs. From this date it continued to lay eggs until 18th November when it ceased to lay but continued to live on, having burrowed its way into a grain of wheat where it remained quiescent. It continued to live in this condition until 23rd April 1915 when it died without having laid any more eggs. In all it had produced 586 eggs.

It would appear from this that one fertilization does not suffice to supply enough spermatozoa to fertilize all the eggs which a female is capable of laying. It has also been found that one male would copulate at least twice. The number of eggs laid per day varies very considerably. It has been noticed that previous to the commencement of oviposition the female feeds vigorously, producing a quantity of the floury frass which is characteristic of the attack of this insect, and then as a rule a large number of eggs is laid daily for some time. Then comes a period of less activity coincident with increased feeding, and this is followed in its turn by a larger daily output of eggs. This is

exemplified in the following table which is the daily oviposition record of a female for one month :—

TABLE X.

Date of observation. 1914						Number of eggs laid
June	1-2	...	...	...	...	20
"	2-3	...	...	...	...	...
"	3-4	...	...	...	...	12
"	4-5	...	...	...	...	10
"	5-6	...	...	...	...	...
"	6-7	...	...	...	...	8
"	7-8	...	...	...	...	4
"	8-9	...	...	...	...	...
"	9-10	...	...	...	...	6
"	10-11	...	...	...	...	19
"	11-12	...	...	...	...	23
"	12-13	...	...	...	...	19
"	13-14	...	...	...	...	21
"	14-15	...	...	...	...	3
"	15-16	...	...	...	...	...
"	16-17	...	...	...	...	22
"	17-18	...	...	...	...	7
"	18-19	...	...	...	...	15
"	19-20	...	...	...	...	10
"	20-21	...	...	...	...	...
"	21-22	...	...	...	...	10
"	22-23	...	...	...	...	12
"	23-24	...	...	...	...	6
"	24-25	...	...	...	...	...
"	25-26	...	...	...	...	...
"	26-27	...	...	...	...	13
"	27-28	...	...	...	...	14
"	28-29	...	...	...	...	16
"	29-30	...	...	...	...	14
TOTAL						284

Oviposition continued steadily until the end of September in some cases but in others it continued until the middle of November, after which all oviposition ceased. The females, however, did not die but lived on, usually buried in the inside of the grain of wheat which they had attacked, and evidently in a hibernating condition for their movements were sluggish and they did not seem to feed much.

The hatching of the eggs. Very little change takes place in the appearance of the eggs until they are nearly ready to hatch when they assume a more opaque white appearance and lose the reddish tinge. The larva emerges by breaking through the egg shell at the end and often remains on the empty shell for some time. The empty egg shell has a collapsed appearance and is of an opaque white colour. As a rule the larva leaves the egg shell untouched

after emerging, but instances have been noticed where the empty egg shells have been partially devoured by the young larvæ. The period, which elapses from the laying of the eggs to the appearance of the larva, varies of course according to the season but during the most active period (May-August) it is usually five days. This is a much shorter period than that given by Chittenden¹ (1911) (14 days, April and May) and Fletcher² (1914) (10 days, season not stated). In the United States the period is likely to be more prolonged because of the more temperate climate, but it is difficult to understand the extended period given by Fletcher, as the climate of Madras should be such as to provide optimum conditions for the development of the eggs.

With the advent of the cold weather the period required for the eggs to hatch increases very rapidly. From a reference to the table given below which shows the period required for the hatching of the eggs from May to November, it will be seen that although the period remained fairly constant till the end of September, yet during October and November the period increased from 11 to 26 days. These latter periods were obtained from eggs laid by a female which had continued to lay until this time although the majority of the females under observation had ceased to oviposit in September.

TABLE XI.

Date of oviposition	Date of hatching	Period
1914.	1914.	
17th May ...	21st May ...	5 Days.
29th " ...	2nd June ...	5 "
10th June ...	15th " ...	6 "
7th July ...	12th July ...	6 "
19th " ...	24th " ...	6 "
12th August ...	17th August ...	6 "
22nd " ...	27th " ...	6 "
14th September	19th September	6 "
30th " ...	6th October ...	7 "
17th October ...	27th " ...	11 "
5th November ...	22nd November ...	18 "
15th " ...	10th December ...	26 "

The larva. Chittenden¹ (1911) gives the following description of the newly hatched larva :—

"The newly hatched larvæ were described as white, slightly yellowish towards the head, head yellowish, ocelli reddish brown, arranged in a triangle, mouth parts brownish, antennæ very short, the head beset with a few long hairs, legs tolerably long, slightly yellowish with long claws. Each of the

¹ *Loc. cit.*² *Loc. cit.*

abdominal segments bears ventrally a number of long hairs and similar hairs are also on the dorsal side of segments 7 and 8. The last segment bears a slightly curved yellow horn, directed backwards. Length a little less than 0.3 mm."

Little needs to be added to this description. The freshly hatched larva (Plate II, figures 3 and 4) is very active and moves quite rapidly about the grains. In this stage, it does not assume the characteristic curved form of the Bostrychid larva, nor is the thorax markedly enlarged.

In the second instar (Plate II, figures 5 and 6) it still retains the shape of the freshly emerged larva and practically the only noticeable difference is the increase in size.

In the third instar (Plate II, figure 7) the larva has now commenced to assume the typical curved form, and the thorax has become much more swollen. There is still no noticeable change in colour.

In the fourth instar (Plate II, figures 8 and 9) the larva reaches its full development. Chittenden's¹ (1911) description of the larva in this stage is as follows :—

"The larva when fully developed is of the characteristic Bostrychine form similar to that of *Dinoderus truncatus*. It is rather more elongate than usual in the *Ptinidae* and more constricted in the middle. The ground colour is white, the head light brown, and the mandibles dark brown, nearly black. The claws of the legs are light brown. The body is covered with minute slender pale brown hairs, which are denser and somewhat longer on the first thoracic and last two abdominal segments.

"The larvæ when lying on their sides somewhat resemble on a smaller scale those of the *Lamellicorns*, the body being curved in the same manner; locomotion in this position is possible but very slow.

"Full-grown larvæ measured about 2.8 mm. in length."

The larva passes through four moults as a rule though one or two cases have been observed where five moultings took place. These results were obtained by rearing the larvæ on flour as of course daily examination of larvæ inside grains would be difficult and the frequent disturbance due to the cutting open of the grain would not have a good effect on the larvæ. Larvæ living exposed in this way took a little longer to pass through their metamorphosis than those which lived inside the grains, this being probably due to the artificial nature of their surroundings. The experiment was also useful in showing that the larvæ can live and mature in floury material of this kind, a point which will be discussed later. The intervals between each successive moult were fairly regular after the first one, but this was usually

¹ *Loc. cit.*

rather extended. This may, however, have been due to the somewhat artificial conditions under which the larva was living rendering it perhaps more difficult to get through the initial stages, but when it had become well established and the first moult safely passed through, then development would proceed faster.

The pupa. The pupa is at first quite white but later brown pigment is laid down in the eyes and trophi. The pupa exhibits the characteristic depressed head and enlarged thorax of the adult. The dorsal surface is covered with hairs.

The pupa lies in the cavity inside the grain which the larva has excavated during its feeding processes. No cocoon of any sort is prepared, and the exuvia and excrement of the larva are pushed into the unoccupied space left in the cavity of the grain at the tail end of the pupa. In the case of the larvæ which were reared upon flour, an elliptical cavity was hollowed out by the larva in the floury material in which it pupated.

The adult. Chittenden¹ (1911) describing the beetle says :—" The beetle is about one-eighth inch long and about one-thirty second of an inch in width, quite narrow being therefore approximately four times as long as wide. The form is nearly cylindrical, the head is comparatively large and prominent and bent down under the thorax in the manner peculiar to most members of the family Bostrychidæ ; the antennæ are also prominent, as are the eyes and the mandibles. The antennæ are ten jointed and terminate in a three jointed club. The colour is dark brown or castaneous and polished throughout."

To this description might be added that the anterior margin of the dome shaped thorax is crenulate and that the surface of the thorax and the elytra is pitted ; the pits on the elytra being arranged in lines giving them a striated appearance.

Viewed from above, the head of the beetle is completely hidden, when at rest, by the over-hanging anterior margin of the thorax, but when the insect is active, the head is raised and protruded to some extent, so that the mandibles and a portion of the head appear in view as is represented in figure 11, Plate II.

The males and females are to all outward appearances exactly similar. There is no noticeable difference in size or in the shape of the antennæ. It is therefore extremely difficult to determine the sex of the newly emerged insects. In carrying out the work on the number of generations passed through, it became imperative to know which were females, and this was done in the following way :—A number of insects was selected from the stock and isolated in tubes. As the insects are very active in the natural state, the

¹ *Loc. cit.*

probabilities are that a female very rarely escapes fertilization and by selecting fairly young insects, which can be determined from their colour, those beetles which laid eggs were females and those which did not were assumed to be males. The newly emerged beetles were then tested with these males and in each case by taking a sufficient number it was possible to obtain fertilized females to carry on the generations.

The adults both male and female are provided with wings which they use, and beetles have often been caught on the wing in storehouses and other places where the insects were present in numbers. This is the only one of the three important Punjab stored wheat insects which the writer has caught flying, although the other two possess wings. The extent to which it uses its power of flight is difficult to determine. It has usually been seen flying in an aimless kind of way about rooms and storehouses where wheat is stored, but has not been taken in the field, though there seems no reason why it should not infect piles of wheat which often lie about in villages near to the store places for some time before the wheat is actually stored. In any case it is probably a fruitful source of infection from one godown or *kotha* to another. This is especially so when they are built close together as is often the case in villages and *mandis*, and particularly so, when one considers the indifferent state of repair in which these buildings are often kept, so that intercommunication between the several rooms or chambers is very easy and would afford no obstacles to the passage of such a small insect as *R. dominica*.

The adult after emerging from the pupal covering remains generally for a few days inside the grain in which it has developed, until it is mature, and then cuts its way out through the side of the grain.

The length of life-history. This of course varies with the season of the year, but the insect is most active from May until August. From September onwards the period of life-history lengthens and in December, January and February the insect merely "marks time," remaining in a hibernating condition in whatever stage it was when the cold weather set in. The shortest period observed was 24 days (June and July 1914) and the average period during the time of general activity is 27 days. This period is again shorter than given by Chittenden¹ (1911) (108 days April 27—August 12) and Fletcher² (1914) (probably less than two months) but neither of these observers had determined the period exactly. It is, however, difficult to understand why Fletcher should have suggested such an extended period, for there does not seem to be any reason why the average period in Madras should not be nearly the same as in the Punjab.

¹ *Loc. cit.*

² *Loc. cit.*

The following table gives the length of life-history for each month in the year during which the insects are active. For the sake of convenience the table commences with the month of May as this is the beginning of the period of activity. The figures given are the actual number of days which elapsed from the laying of the egg to the emergence of the beetle from the pupa case. This last was determined by cutting open the grains about the time when pupation should have taken place, for, as has been mentioned previously, the adult in nature usually remains inside the grain for some days after emerging from the pupa case before cutting its way out :—

TABLE XII.

Date of oviposition	Date of emergence of adult	Period
1914	1914	
27th May ...	20th June ...	35 Days.
29th " ...	1st July ...	32 "
3rd June ...	3rd " ...	31 "
25th " ...	18th " ...	24 "
10th July ...	4th August ...	26 "
12th August ...	8th September ...	28 "
22nd " ...	19th " ...	29 "
14th September ...	20th October ...	37 "
23rd " ...	13th November ...	52 "
6th October ...	6th April 1915 ...	183 "

The number of generations per annum is probably five. In carrying out the investigation to determine the number of generations, some days were allowed to elapse between the successive generations to compensate for the period during which the insect usually remained inside the wheat grain in which it had developed, before breaking its way out. Below is given a typical series of generations :—

TABLE XIII.

Generation	Date of oviposition	Date of emergence of adult	Period
	1914	1914	
First ...	1st April*	17th May	41 Days.
Second ...	4th June	7th July	34 "
Third ...	11th July	7th August	28 "
Fourth ...	22nd August	18th September	28 "
Fifth ...	6th October	6th April 1915	183 "

* This date is only approximate. The larva emerged from the egg on 7th April.

The effect on the grain. The attack of *R. dominica* is quite characteristic, and with a little practice can be distinguished from that of *A. undulatus* or *C. oryzae*. The most noticeable part of the damage is that effected by the adults. Grains are seen in which the whole of the starchy interior has been eaten away leaving the pericarp of the seed empty and riddled with large

irregularly shaped holes. A large amount of white floury frass soon accumulates, for the insect spoils almost as much, if not more, of the grain than it consumes by reducing it to the condition of flour which, as has been mentioned previously, probably affords a means of support for the young larvæ until they can find grains suitable for them to bore into.

As with *A. undulatus*, experiments were made to determine whether the freshly emerged larvæ could attack and bore into perfect grains, or whether they could only attack those which were in some way damaged. The results of these experiments, although one or two exceptions occurred, go to show that the newly hatched larvæ cannot enter a wheat grain which has the pericarp complete, but the smallest crack or abrasion in the pericarp which has removed the hard outer skin so that the softer underlying tissues can be reached, seems to be sufficient to enable the larva to make its way into the grain. If, however, the pericarp is entire, even fairly mature larvæ are unable to penetrate into the grains. For example three larvæ, one month old which had been reared on frass, were placed along with three grains of which the pericarp was entire, and they failed to enter the grains and ultimately died; two, three days after being put in, and the remaining one on the fourth day. In another instance out of four larvæ which had been feeding on frass for seven weeks, only one succeeded in penetrating a grain and the others died without having done so.

From repeated observations it was found that the freshly hatched larvæ had no difficulty in entering grains which had been sliced, or the pericarp removed in any way, and in rearing larvæ in the investigations upon the life-history of the insect, a small hole was made in the grain with a needle to afford an easy ingress for the larva. Under natural conditions although the young larvæ may find some difficulty in discovering grains which they can penetrate, yet the activities of the adults must render a large number of grains liable to attack by the larvæ, and in this the males would be as effective as the females; and more than this, the frass, which the attack of the adults produces, would afford a means whereby the young larva would be able to tide over the earlier stages, if it was not successful in finding a suitable grain to attack at once.

Calandra oryze, Linn.

PLATE III.

Of all the insects which attack stored wheat *C. oryze* has perhaps received most attention from entomologists owing to its practically world-wide distribution and its importance as a granary pest in other countries. It is not proposed

PLATE III.

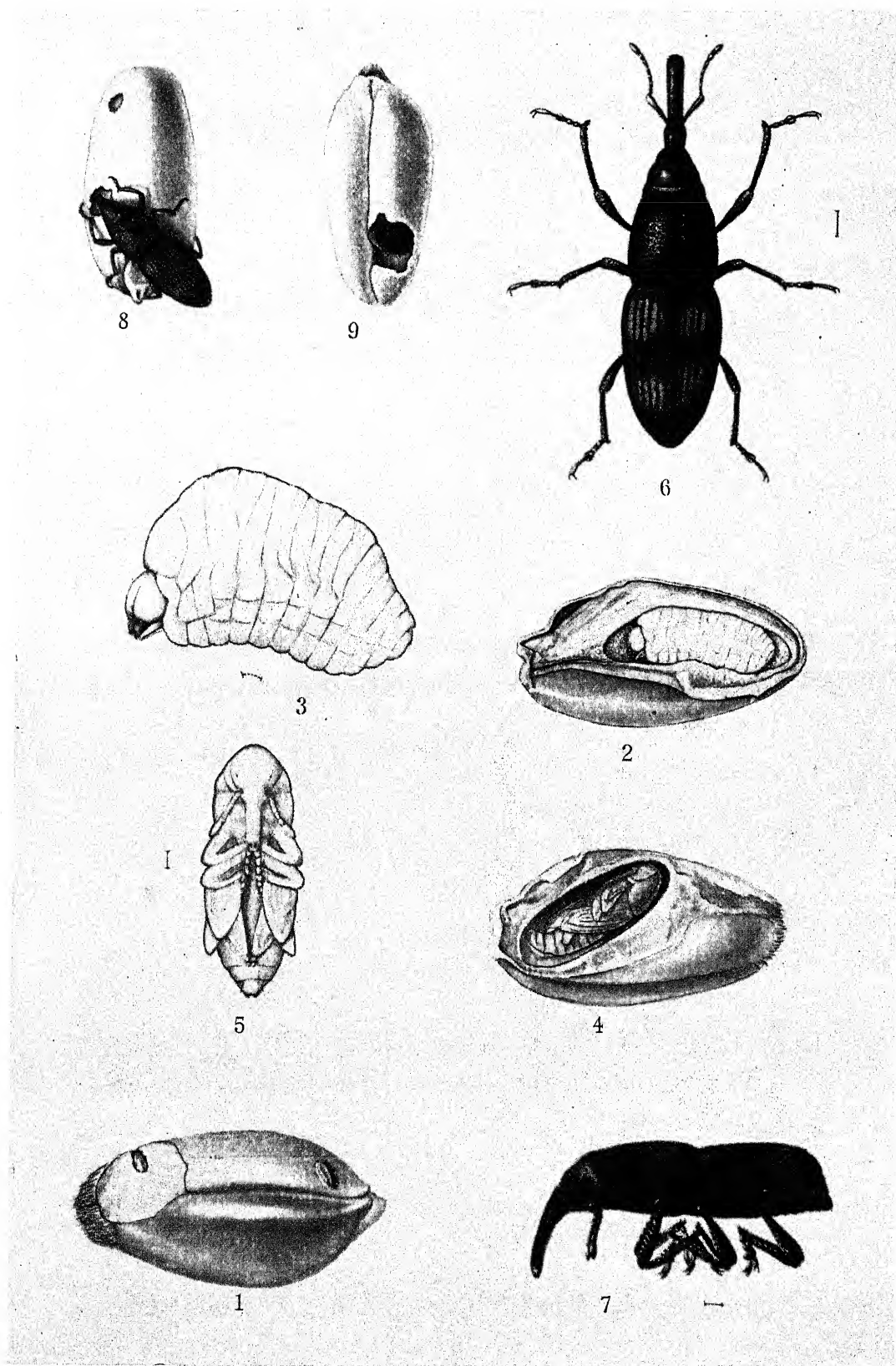
Calandra oryzae

- Fig. 1. Eggs laid on a wheat grain ($\times 8$).
 2. Larva feeding inside a grain ($\times 8$).
 3. Larva removed from grain ($\times 16$).
 4. Pupa in natural position inside grain ($\times 8$).
 5. Pupa removed from grain, ventral view ($\times 16$).
 6. *C. oryzae* from above ($\times 16$).
 7. *C. oryzae* from side ($\times 16$).
 8. Beetle gnawing into wheat grain ($\times 8$).
 9. Adult inside a wheat grain ($\times 8$).
- The hair-lines alongside the figures show the natural sizes.

Calandra oryzae, Linn.

PLATE III.

Of all the insects which attack stored wheat *C. oryzae* has perhaps received most attention from entomologists owing to its practically world-wide distribution and its importance as a granary pest in other countries. It is not proposed



CALANDRA ORYZÆ.

here to summarize what has been previously written about this insect by observers in other countries, as much of this literature is not available here; but it will be useful to refer to what has been done with this insect by Indian observers as recorded in the rather scanty literature on Indian economic entomology. The earliest paper of value is that by Cotes¹ (1888) which gives a short account of the life-history of the insect and discusses various remedies. Lefroy² (1906 and 1909) gives some details of the life-history of the insect. Fletcher³ (1911 and 1914) gives more details of its life-history and discusses the relation of dryness and moistness to the development of the insect. Although therefore quite a lot is known about this insect in other parts of India, very little is known with regard to its habits in the Punjab, so that for the purpose of this investigation only those points which are of importance to the problem from the point of view of the conditions which obtain in the Punjab have been considered.

The egg. The egg as described by Fletcher³ (1911) is laid in a groove or pit prepared for it by the female in the surface of the grain. Any situation on the grain may be selected by the female and it has not been observed, as stated by Fletcher, that special preference for the hairy apex of the grain is shown. Under ordinary circumstances the eggs are always laid buried in the grain but eggs have occasionally been found laid exposed on the wheat grain. These did not hatch, however.

The number of eggs laid by this insect under Indian conditions has never been determined. Hinds and Turner⁴ (1911) in their account of the insect give the maximum number observed as 417 and the maximum number laid in twenty-four hours as 20. These authors do not say by what method the number of eggs was determined, whether the eggs were cut out daily or not. It was found too laborious to cut out the eggs in each case, nor was counting the scars made upon the surface of the grains reliable, as every scar did not always denote the presence of an egg. The following method was therefore adopted, which it was hoped would give a fair approximation to the number laid. A virgin female was taken and confined with an active male and supplied daily with 20 fresh grains of wheat; the old ones, in which the female had presumably laid eggs, were then removed, placed in a test tube, and kept under favourable conditions for a sufficient time to allow the eggs to develop into

¹ Cotes, E. C. A preliminary account of the wheat and rice weevil in India. *Notes on Economic Entomology*. No. 1. Government Press, Calcutta.

² *Loc. cit.*

³ Fletcher, T. Bainbrigge. "Weevil and dry wheat." *Agricultural Journal of India*. Vol. VI, pp. 333-343.

⁴ Hinds and Turner. *Calandra oryzae* in Alabama. The life-history of the rice weevil. *Journal of Economic Entomology*, Vol. IV, pp. 230-236, Part 7.

easily distinguishable larvæ. The grains were then cut open and the number of larvæ counted, this number being taken as the number of eggs laid. The results obtained, however, were not very encouraging for the greatest number recorded was 60 between 9th and 31st October 1914, after which date no more eggs were found although the female continued to live for some time afterwards. The largest number recorded in one day was 19. These results are much smaller than those given by Hinds and Turner¹ (1911) and evidently require further investigation.

The larva. The larva has been figured and described several times before by various authors. It is a small legless grub, yellowish white in colour with a yellowish brown head. In its natural state it is slightly curved giving it a humped appearance. Hinds and Turner¹ (1911) state that there are three stages in the larval history, determined by differences in the measurements of the head. This point could not be verified in the same way that the number of moults of *R. dominica* were ascertained, as the larvæ would not live on flour.

The larvæ possess a distinct advantage over those of *A. undulatus* and *R. dominica* for, since the egg is laid beneath the surface of the grain, the larva when it hatches out has a place already provided for it where it may attack the grain, and it has not to search for suitable food as is the case with the other two insects. If it had to do so, as would happen in the cases where the eggs were laid on the surface of the grains, it would be at a distinct disadvantage for, being legless, its scope for locomotion would be very limited.

The pupa. This is a typical curculionid pupa and all the characteristics of the adult can be clearly discerned. Hinds and Turner¹ give the duration of this stage as between three and nine days, and the average as six. Fletcher gives the period as six days in warm weather. In Lyallpur during the time when the insect is most active, that is August and September, the time required for the emergence of the pupa is about 5 or 6 days but as the weather gradually gets colder, this period lengthens and at the end of November may be as long as 14 days. A few examples are given below :—

TABLE XIV.

Date of pupation		Date of emergence of adult	Period in days
1914.		1914.	
9th October	...	14th October	6
24th "	...	30th "	7
4th November	...	11th November	8
20th "	...	3rd December	14

¹ *Loc. cit.*

The adult. This is the most easily recognizable of all the insects which infect stored wheat in the Punjab, and is, moreover (with the exception of *C. granaria* which is unimportant, owing to its comparative rarity), the only true "weevil" among them all. Native dealers in some places have learned to distinguish it from the other beetles and call it the *sund wali susri* from its pronounced snout or trunk. It is brownish-black in colour, becoming progressively darker as it becomes older. In its younger stages it may even be quite light brown and is not easily distinguished by its colour from *C. granaria*, but the four reddish brown spots on the elytra and the characteristic pitted appearance of the thorax and elytra render it easily distinguishable.

The sexes are also easily distinguishable, as stated by Hinds and Turner¹ (1911), by the length and breadth of the snout, that of the male being shorter and broader than that of the female.

A curious characteristic of this insect has been noticed. The beetles as a rule lie hidden among the grains, but if the wheat is disturbed, a large number immediately comes out on to the surface of the wheat walking about actively as if seeking to escape from some danger. It has also been noticed that the adults are capable of walking up smooth vertical surfaces with ease, differing in this respect from *A. undulatus* and *R. dominica*.

During copulation the male mounts the female from behind retaining its hold by the front legs the tibiae of which are armed with strong spines. The females will take the male more than once, as the following example shows: A male and female were put together with some grains of wheat on 21st February 1914. On 1st March they were observed to be coupling, but no eggs were found subsequently. On 7th March they were again seen to be pairing and again on the 13th. The female died on 16th and the male on the 18th and on 28th the grains were cut open but no larvæ or eggs were found. The insects had been kept the whole time in an incubator at 30° Cent. (86° Fahr.) which is an average warm weather temperature, so that the non-production of progeny is difficult to understand.

The length of life-history. No accurate figures are available of the length of time occupied by this insect in passing through its various stages in India. Fletcher² (1911) gives some figures, but these cannot be taken as the determination of the actual length of life-history, since they are based upon the dates when the parents were put into the jar of wheat. This, however, cannot be taken as a criterion for the date of oviposition, for the eggs may not have been laid for some days after the parents were put in among the wheat, and there

¹ *Loc. cit.*

² *Loc. cit.*

is no reason to suppose that the period between the infection of the wheat and oviposition of the female would be the same in each case. It is clear therefore that these figures cannot be relied upon. A report by Hooper¹ (1913) is quoted by Noël Paton² (1913) giving some figures of the length of life-history, but in these again no measures were taken to ascertain accurately the date of oviposition. However, 29 days (May and June) is given as one of the periods observed, and this is considerably shorter than the shortest period given by Fletcher (34-36 days June-July) although the climate of Calcutta is not so very different from that of Pusa.

In Lyallpur *C. oryzae* behaves in a peculiar manner. During the hot dry weather the majority of the insects die off under ordinary circumstances. At the end of the cold weather a large number of beetles was observed to be leaving a bag of wheat which was badly attacked by them, and to be crawling up the walls of the room in which the wheat was stored. This migration continued until there was scarcely a specimen to be found among the wheat. A large number of these died, but doubtless many of them found suitable lurking places in which to hide until the advent of more favourable conditions. In bottles of wheat in which the insects were allowed to breed and which were being kept to supply insects for other experiments, the insects merely died off, escape from the bottle being impossible. Breeding had apparently ceased entirely, and this was borne out by experiments which were being tried, for at this time of the year all the attempts made to induce the insect to breed were unsuccessful. Even altering the moisture conditions did not have much effect, for a number of pairs of insects were kept in an atmosphere of high humidity, but although this prolonged the life of the insects, breeding only took place in one or two instances, and then not to any large extent. Reducing the temperature and increasing the humidity was more successful. Under natural conditions, however, breeding did not take place until after the rains had come and it was not until the beginning of September that records could be obtained.

This is not the state of affairs which obtains in all parts of the Punjab, for in the moister places (Gurdaspur, Amritsar, etc.), it was found in the beginning of August that *C. oryzae* had been active for some time, but in these parts the rainfall is higher than that of Lyallpur, and July is usually a wet month; and this would produce conditions favourable to the development of the insect.

¹ Hooper, D. Damage by wheat weevil. Appendix N, *Indian wheat and grain elevators*, by F. Noël Paton.

² Noël Paton, F. *Indian wheat and grain elevators*. Government Press, Calcutta.

The way in which this insect reacts towards the conditions of moisture in the wheat has been recorded by Lefroy¹ (1909) and Fletcher (1911),² and will be dealt with again subsequently (see page 261 et seq.).

When conditions in Lyallpur were such that the insect could breed under natural conditions, this went on at quite a rapid rate, the period between the laying of the eggs and the emergence of the adult from the pupa case being as short as 22 days. This rapid development went on uninterruptedly until the end of September. In October and November the period required for development lengthened until it had reached a maximum of 50 days. By December and January the period had extended to a maximum of 85 days (2nd November 1914—25th January 1915) and after this, development ceased, the insects remaining in the larval stage in the grains of wheat. The following table gives some examples of the period required for development at different periods :—

TABLE XV.

Date of oviposition		Date of emergence of adult	Period in days
1914		1914	
12th September	...	2nd October	21
19th "	...	11th "	23
2nd October	...	29th "	28
20th "	...	4th December	46
2nd November	...	25th January 1915	85
3rd December	...	5th April 1915	124

The number of generations. The number of generations in the year is determined by the period during which the conditions are suitable for the breeding of the insect. This varies with different parts of the Punjab. At Lyallpur where the insect begins to breed so late in the year there are probably only three or possibly four generations.

The effect on the grain. As in the case of *R. dominica* the most noticeable effect is that produced by the adults. The effect of the activities of the larvæ on the grains is not easily distinguishable since they do all their work inside the grains. The adults gnaw small almost circular holes into the grains, their long snouts being particularly adapted for the purpose. They do not, however, consume the entire starchy contents of the grains in the way that *R. dominica* does, and in this way the attacks of the two insects can be distinguished.

¹ *Loc. cit.*² *Loc. cit.*

The amount of damage which this insect is capable of doing has been discussed by several writers. Hooper¹ (1913) says that the damage effected by 50 weevils (sexes not stated) and their progeny in 100 grams of hard wheat was a loss of 26% by weight, 65% of the grains being found to be weeviled; the experiment having extended from 12th April to 12th July, 92 days. Fletcher² (1911) also states that "a large number of weevils" put into 1 seer (2 lb.) of wheat effected in 167 days a loss by weight of roughly one-third, but makes the reservation that it is difficult to estimate the actual damage. It is clear that the figures obtained from these experiments although of scientific interest cannot be taken as an indication of the amount of damage caused by the insect under normal conditions, since the conditions under which they were carried out do not in any way approximate to those under which the insect usually lives, and the relation between the number of weevils and the quantity of wheat infected is disproportionately exaggerated. In fact it is almost impossible to elaborate an experiment, or series of experiments, which would give any reliable data, because of our ignorance of the individual conditions which obtain in each case. The factors which control the final result are so numerous and so many of them are unknown, that any attempt to approximate to them is practically impossible. No attempt was made therefore to do this experimentally, but information on the subject was sought from grain dealers and others and the question will be dealt with in another place.

Tribolium castaneum Hbst.

PLATE IV.

As has been previously stated, this insect is not an active agent in the destruction of good wheat but lives on grains damaged by other insects and in the dust or frass produced by their attacks, and in reality it is a flour beetle. Lefroy³ (1906) mentions it as "feeding upon grain, biscuits, and having a great liking for dried insects" and calls it the red grain beetle. The same author records it again⁴ (1909) as "reared from wheat grains, wheat flour and oat meal as well as dried insects," but no details of its life-history are given. Fletcher⁵ (1914) gives some details of its life-history and gives it the status of "a serious pest of stored products not only by the actual quantity eaten but on account of the extremely nauseous smell and taste which it communicates to infected substances."

¹ *Loc. cit.*

² *Loc. cit.*

³ *Loc. cit.*

⁴ *Loc. cit.*

⁵ *Loc. cit.*

PLATE IV.

Tribolium castaneum.

- Fig. 1. The egg ($\times 13$).
 2. The freshly emerged larva ($\times 13$).
 3. The fully grown larva ($\times 10$).
 4. The pupa. Ventral view ($\times 13$).
 5. The adult ($\times 13$).
 6. The egg ($\times 13$).
 7. The freshly emerged larva ($\times 13$).
 8. The fully grown larva ($\times 10$).
 9. The pupa. Ventral view ($\times 13$).
 10. The adult ($\times 13$).

Latheticus oryzae.

11. The egg ($\times 13$).
 12. The freshly emerged larva ($\times 13$).
 13. The fully grown larva ($\times 10$).
 14. The pupa. Ventral view ($\times 13$).
 15. The adult ($\times 13$).

Tribolium castaneum Hbst.

Lamphileus sp.

16. The egg ($\times 13$).
 17. The freshly emerged larva ($\times 13$).
 18. The fully grown larva ($\times 13$).
 19. The pupa. Ventral view ($\times 13$).
 20. The adult ($\times 13$).
 21. The small figures by the side of the larger ones indicate the natural sizes of the insects.
- "As has been previously stated, this insect is a destruction of good wheat but lives on grains damaged in the dust or mass produced by their attacks, and is Lefroy¹ (1906) mentions it as feeding upon grain, b liking for dried insects and calls it the red grain beetle. The same author records it again (1906) as "reared from wheat grains, wheat flour and oat meal as well as dried insects," but no details of its life-history are given. Fletcher⁵ (1914) gives some details of its life-history and gives it the status of "a serious pest of stored products not only by the actual quantity eaten but on account of the extremely nauseous smell and taste which it communicates to infected substances."

¹ Loc. cit.

² Loc. cit.

³ Loc. cit.

⁴ Loc. cit.

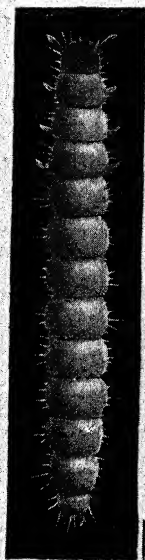
⁵ Loc. cit.



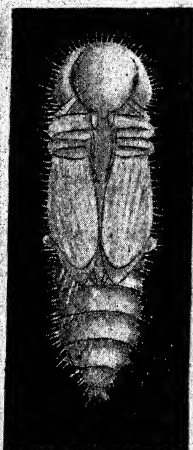
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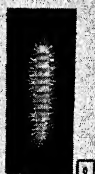
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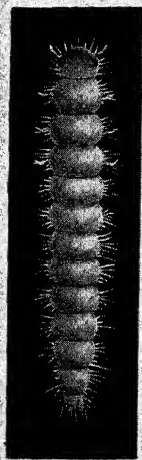
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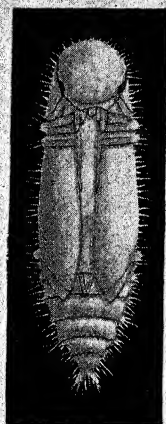
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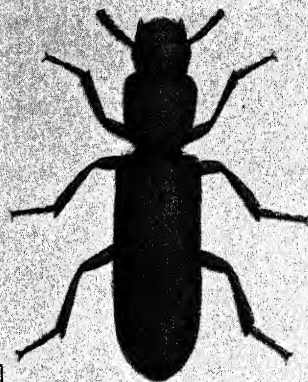
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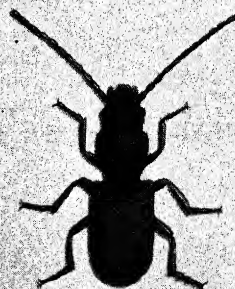
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13



14



15



The egg. The egg is small, slender, cylindrical in shape, rounded at both ends and of whitish colour. The eggs are laid singly among the dust and floury matter in which the insects live and as they are sticky when they are laid they become covered with small particles of dust and flour which adhere to the surface. This renders the eggs very difficult to find.

The number of eggs laid by a female was not determined, but this is probably considerable judging by the rate at which this insect will increase under favourable conditions.

The larva. The freshly-emerged larva is about 1.0 mm. long, yellowish-white, slender, cylindrical, the thoracic segments narrower than the abdominal ones. The terminal segment is furnished with a pair of spine-like appendages, and all the segments have on them a number of fine hairs. When freshly emerged, the larva is beautifully translucent as if it were made of glass. After a while it becomes opaque with the ingestion of food. The most remarkable thing about the development of the larva is the short period between the successive moults and the number of them. The first moult often occurs the day following the emergence of the larva, and in the earlier stages the moults may succeed one another at intervals of two days. In the later stages a little longer period intervenes. The following table gives two examples of this :—

Date of hatching	Date of first moult	Date of second moult	Date of third moult	Date of fourth moult	Date of fifth moult	Date of sixth moult	Date of seventh moult
18 Aug. 14	19 Aug. 14	22 Aug. 14	24 Aug. 14	26 Aug. 14	28 Aug. 14	1 Sept. 14	5 Sept. 14
23 Sept. 14	24 Sept. 14	27 Sept. 14	30 Sept. 14	3 Oct. 14	7 Oct. 14	11 Oct. 14	19 Oct. 14

The usual number of moults is seven as recorded above, but variations have been noticed, eight moults being recorded in one case, and six in another.

As development progresses the colour of the larva changes until in the later stages it assumes a reddish-yellow colour, the colour being particularly developed in the head and the appendages of the terminal segment.

The full-grown larva is 6.3 mm. long and is of a general reddish-yellow colour. The head is much darker in colour and also the appendages of the last abdominal segment. The shape closely resembles that of the earlier stages. The eyes are distinct and the antennæ well developed. All the segments are furnished with fine hairs.

The pupa. This stage presents no striking features. The pupa is naked, yellowish-white, the dorsal surface covered with pale-coloured hairs and the

terminal segment with two spine-like processes resembling those possessed by the larva except that they are not pigmented.

The adult. The mature insect is a small reddish-brown beetle 3.5 mm. long. The head, thorax, and abdomen are distinct and the antennæ well developed.

The insect is very common in the wheat stores in the Punjab, sometimes being present in extraordinary numbers in wheat which has been attacked by other insects. This is especially so when the wheat has been damaged by *C. oryzae* or *R. dominica*, both these insects producing a large quantity of dust and frass upon which the insect can live, but as has been previously pointed out this insect does not damage good wheat.

The length of life-history. This is apparently short under favourable conditions, the shortest period observed being 26 days (August-September). Considerable variation was noticed and in one case the period was extended to 59 days (August-October).

Latheticus oryzae Waterh.

PLATE IV.

Although the specimens from which the original description of this insect was made came from Calcutta (Chittenden 1911), little or no attention has been given to it by Indian observers. Lefroy does not mention it in either of his books, and Fletcher¹ (1914) includes it in a list of insects attacking stored produce, but gives no details regarding it. It occurs fairly commonly in wheat stores in the Punjab, and a number of places in which it has been found are recorded on page 168.

The egg. The egg is shorter and broader than that of *T. castaneum* and ovoid rather than cylindrical in shape. It is opaque and the surface is smooth.

The larva. The freshly-emerged larva is very similar to that of *T. castaneum*, in fact in this stage it is very difficult to distinguish between them. The general colour is a yellowish-white with a slightly darker pigment on the head and appendages.

The full-grown larva, however, is easily distinguishable from that of *T. castaneum* being slightly shorter in length and lighter in colour, especially the head and appendages. The spine-like appendages to the last segment are also different in shape and lighter in colour. The segments are furnished with numerous light-coloured hairs.

¹ *Loc. cit.*

The number of moults passed through by the larva was found to vary from six to nine. The earlier moults followed in rapid succession, but the period between the later moults became gradually more extended.

The pupa. This stage is easily distinguishable from the corresponding stage of *T. castaneum*. The pupa is on the whole more slender, the thorax is not so clearly differentiated from the abdomen, and the wing cases are larger. In other respects the two stages are very similar.

The adult. Although closely resembling *T. castaneum* in many respects, yet careful examination reveals many differences between the two beetles. Chittenden¹ (1911) characterizes the species as:—"General form of *T. ferrugineum*, F., but rather narrower and the head relatively longer and broader and more square in general outline. Forehead and the middle of the epistoma gently convex, the former not very thickly but very distinctly punctured, about twice as broad as long, obliquely (but not much) narrowed anteriorly, declivous in front, impressed at the sides, emarginate in front, the ocular canthus not much encroaching upon the eyes. Antennæ rather short, thickest at the eighth joint, so that their general outline is somewhat fusiform. Thorax very little broader than the head across the eyes, a little narrower behind, very distinctly but not very thickly punctured: the angles obtuse, the sides somewhat straight very finely margined. Elytra as wide as the broadest part of the thorax, parallel, their surface somewhat uneven or wrinkled, each elytron with four or five scarcely impressed lines, with somewhat large punctures, the lines somewhat irregular or here and there interrupted, legs rather slender (Waterhouse)."

To this description no additions are necessary.

Length of life-history. This has only been worked out in a general way as the insect is not an important one. The shortest period observed was 25 days (August-September 1914), but during the same period the length of life-history was as extended as 39 days. The larvæ thrive better on ordinary flour than on the floury frass produced by other insects.

Læmophlæus sp.

PLATE IV.

The specimens of the insect found in the Punjab are apparently different from those of *L. pusillus* and its identification is still uncertain.

The egg. The egg is small, slender, cylindrical in shape and rounded at both ends. In colour it is a beautiful translucent white. The length is 0.6 mm.

¹ *Loc. cit.*

The larva. The freshly-emerged larva is about 0.7 mm. long, yellowish white, the head, and the spine-like appendages, on the anal segment, reddish brown. The larva is cylindrical in shape tapering a little to each end.

The full-grown larva, however, is different in shape. The head and thorax are narrow, gradually widening posteriorly, but the segments of the abdomen are markedly longer and broader, becoming progressively so until about the fourth segment which is the broadest, and then tapering away again to the terminal segment which is furnished with two pigmented spine-like appendages. The segments show a gradation in colour along the edges which gives them a margined appearance. Each of the abdominal segments is furnished with a few fine hairs. The general colour of the larva is a creamy-white with the exception of the terminal segment which is a reddish-brown. The full-grown larva is 4 mm. long and 0.5 mm. across the widest part of the abdomen.

In the course of its development the larva casts its skin four times, the last moult revealing the pupa.

The pupa. This is a curiously contracted, angular looking stage, and is small compared with the larva. It is creamy-white and is about 1.75 mm. long. Beyond its rather remarkable appearance it has no other noticeable characteristic.

The adult. The mature insect is a small flattened beetle about 2.0 mm. long. The general colour is a fuscous brown but the head and thorax are darker in colour, the antennæ are filiform.

The length of life-history. From the few examples reared through, there was found to be a good deal of variation in the period occupied by the insect in completing its development. The shortest period noticed was 36 days (September-October 1914), but even during this period of the year the number of days was as many as 75 in one case.

The adult beetles are sometimes capable of living for very extended periods. For example, a male and a female beetle were found copulating on 16th March 1914 and were isolated. One beetle lived until 21st May, and the other died only on 10th November. During this time the insects had been fed on flour, and although soon after they were isolated a number of larvæ were seen, these apparently did not mature. The females apparently pair with the males several times during their existence. A male and female, found copulating, were isolated on 17th March 1914. On 4th April they were observed to be again coupling, and this was also noticed on the following

dates :—5th, 6th, 7th, and 17th May and 11th June. The male died on 29th June and the female on 10th August.

Sitotroga Cerealella Oliv.

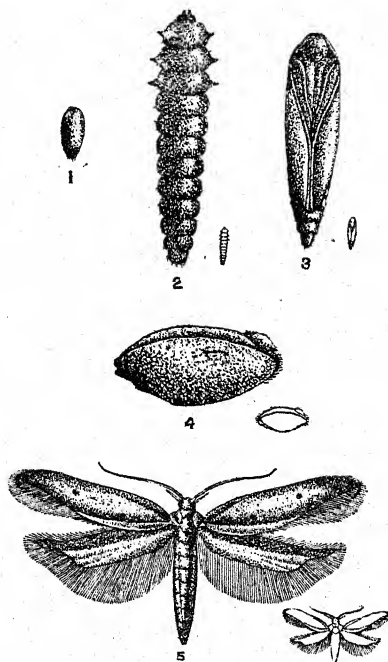


FIG. 1.

This small moth was found fairly commonly in the Gurdaspur district, but does not seem to be important in other parts of the Province.

The egg. This is small, pinkish in colour, about 0·5 mm. long, ovoid in shape, one end being wider than the other, and both ends are rounded. The surface of the egg-shell is striated longitudinally. The number of eggs laid by each female is about one hundred. Of three females kept under observation one laid 118 eggs, another 87 eggs and the third 80. The eggs are laid in clusters in any convenient position, often in the groove in the grain or in holes in the grains made by other insects.

The larva. The freshly-emerged larvæ are very small and extremely active. They crawl about the grains in search of a suitable one to attack, and generally effect an entrance through a crack or abrasion in the pericarp.

Having once entered the grain the larva remains inside it for the remainder of its development.

The full-grown larva is a small grub or caterpillar about 5.0 mm. long. The head is small, light brown or yellowish-brown in colour. The thoracic segments are furnished with three pairs of true legs, and there are also four pairs of prolegs, one pair on each of the third to sixth abdominal segments.

When the larva is ready to pupate it extends the cavity which it has excavated to the outside of the grain, and a small hole is gnawed out on the surface of the grain. The larva then spins a thin cocoon of silken material, and one end of this cocoon projects through the hole made in the surface of the grain, giving the appearance of a small blister projecting from the surface. The larva then pupates inside the cocoon. This piercing of the side of the grain is a provision to enable the moth, when it emerges from the pupa, to leave the grain easily, for the moth itself is much too delicate to force or make its way through the tissues of the grain without some provision being made for it.

The pupa. This stage is a typical lepidopterous pupa, and offers no special points for remark.

The adult. The mature insect is a small moth 6.25 mm., from tip to tip of the wings, which are delicate and heavily fringed with hairs on the posterior margin. The antennæ are long and filiform, practically free from hairs, and the labial palps are long and project anteriorly from the head.

The moth emerging from the pupa breaks through the silken cocoon where it projects beyond the surface of the grain, and creeps out. It then gradually makes its way up between the grains to the surface of the wheat where it pairs. The female then lays her eggs and dies. A very efficient way therefore of preventing the increase in numbers of this insect, would be either to fill the receptacles containing the wheat right to the top, so that no space would be left at the top for the insects to pair in, or to produce the same state of affairs by covering the wheat with gunny bags or *chittais* and fill up the space with *bhusa* (broken wheat straw).

The length of life-history. In the period during which this insect was kept under observation, the length of life-history was found to vary from 30 days (9th September—8th October 1914) to 142 days (12th October 1914 to 2nd March 1915). This latter extended period was perhaps exceptional and the larva was probably in a state of hibernation during the greater part of it, for several moths emerged after a period of between 50 and 60 days, the eggs

for all of them having been laid on the same date, *viz.*, 12th October 1914. Between September and December the length of life-history gradually increases from 30 days to about 65 days and then the larva probably goes into hibernation.

PARASITES.

In examining wheat which was badly attacked by *R. dominica* and *C. oryzae* a number of tiny black Chalcid parasites was often seen. In cases where large numbers of these two beetles were being reared for experimental purposes, the parasite was often noticed. No appreciable diminution in the number of the beetles was, however, ever observed that could be attributed to the activities of the parasite, and from general observations in wheat stores its effect as an efficient check upon the multiplication of the beetles never appeared marked. In any case, the parasite could not be used as a practical means of keeping the wheat free from the attack of the beetles, so that no further observations were made upon it. No hymenopterous parasite was ever observed attacking *A. undulatus*.

GENERAL REMARKS.

From the records which have been given above it will be seen that the three insects, *A. undulatus*, *R. dominica* and *C. oryzae*, which are the most important agents in causing damage to stored wheat in the Punjab, offer many differences as well as resemblances, and the grain always seems to be liable to the attack of one or other of them, no matter under what conditions it is stored. As has been mentioned previously, the relative importance of the three insects varies from place to place depending very largely upon the humidity of the place in question. It is very difficult to say therefore which is the most important insect of the three, or which is responsible for the greatest loss, but of the three it may be said that *A. undulatus* seems to possess the greatest capacity for withstanding adverse conditions. It is handicapped however from the point of view of rapid multiplication by the comparatively small number of eggs laid by the female, and in this respect *R. dominica* and *C. oryzae* possess a distinct advantage. In general, therefore, the attack of *A. undulatus* is as a rule continuous and steady while that of *C. oryzae*, and probably *R. dominica* also, is somewhat discontinuous, depending upon whether conditions are favourable or not, but when things are satisfactory, they can do a great deal of damage in a short time. This bears out the experience of grain dealers who say that when grain becomes attacked by *susri* (meaning *C. oryzae* and *R. dominica*) then a great deal of damage is effected in a short time, but that *khapra* (*A. undulatus*) works more slowly.

How infection takes place. The question often arises how stored grain becomes infected. As far as the conditions under which the ordinary grain dealer stores his wheat are concerned, infection invariably results from the storehouses and godowns containing numbers of insects when the wheat is put into them. It has been pointed out above, how the larvæ of *A. undulatus* hibernate in the cracks and crevices in the walls of storehouses and the same thing applies to the adults of *C. oryzae* and *R. dominica*. It is therefore no matter for surprise, when the perfunctory cleaning process to which the grain stores are usually subjected is considered, that the newly-stored wheat becomes infected at once. This is probably the most important source of infection under the methods of storing wheat at present in vogue in the Punjab, for it is almost impossible to conceive of a building which would offer more convenient lurking places for insects, than the ordinary godown or *kotha* with its walls of imperfect masonry, often covered with mud plaster full of cracks and crevices, and the general indifferent state of repair in which the places are kept.

Apart from these considerations the grain is probably open to infection in other ways. All three insects possess wings in the adult state and *R. dominica* has often been caught flying, and though the other two have not, yet there does not seem to be any reason why they should not. None of the insects, however, have been found attacking wheat in the field or on the threshing floor, though here again, considering the time wheat often lies about in the open before it is stored, it is not impossible that adults may visit it and deposit eggs among the grains. Samples of wheat from threshing floors have not, on examination, confirmed this, and it is probable that the fact that the heaps of grain are usually left in the sun, would prohibit the advent of the beetles, as these insects are essentially inhabitants of houses and store places and not outdoor insects. In any case it is certain that in the Punjab where wheat godowns are often built in rows, insects pass from one chamber to another and extend their depredations in that way.

THE EXTENT OF THE DAMAGE CAUSED BY THE INSECTS.

It has been stated above that no experiments were carried out to test the amount of damage caused by these three insects owing to the practical difficulty of reproducing the extremely varied conditions under which the insects live in nature, and unless this is done the figures obtained are of little practical value. Enquiries were made, however, from grain dealers in the

various places visited, as to the amount which they reckoned to write off each year as loss due to insect attack. The replies, as expected, were varied, some being as small as two per cent. and others as much as five or seven per cent., and the general impression was that the average loss per annum was about two and-a-half per cent. All were practically unanimous in saying that *susri* (*C. oryzae* and *R. dominica*) when it occurred, produced more loss than *khapra* (*A. undulatus*), but as has been pointed out *A. undulatus* works more continuously than the other two and is perhaps responsible for more general damage than the others. That it is sometimes responsible for considerable damage is shown by some figures supplied by Rai Sahib Sewak Ram of Gangapur, who during the season 1914-15 lost 300 maunds of wheat out of 5,000 maunds, chiefly owing to the depredation of *A. undulatus*.

CHAPTER II.

FIRST SERIES OF CHEMICAL EXPERIMENTS.

IN 1911 some experiments were started at Lyallpur to ascertain if any simple and easy method could be devised for immunizing stored grain against the attacks of insect pests of the "weevil" type.

Such method must *a priori* aim at simplicity, cheapness, and freedom from danger, and must leave the grain in an undamaged condition both as a food and for seed purposes. Since these insects are found for the most part in mud huts or other similar dirty places used as granaries by the Punjab villager, one of the first tests made was the substitution of a cheap galvanized iron bin for the common store which is usually only the earthen floor of a mud hut. In order to keep down the cost of construction the bin was made of thin galvanized iron (.022" thick No. 24 B.W.G.). This runs about 106 square feet to the cwt. and costs at Lyallpur Rs. 13/- per cwt. They were made cylindrical in shape; one bin being 8 feet deep with a diameter of $5\frac{1}{2}$ feet and the other $7\frac{1}{2}$ ft. deep with a diameter of $6\frac{1}{2}$ feet. Both were supported on the outside by a roughly made mud wall about twelve inches thick. The bins were roofed over with iron sheets to prevent the rain water getting in, but as the roof did not project over the walls to a sufficient extent the water was blown in under the eaves during the monsoon rains in the first season. This defect was afterwards rectified.

One of the principal objects of these bins was to test the lethal effect of carbon dioxide gas on the weevils and so all joints were soldered after the edges of the plates had been riveted in order to prevent the gas from leaking. Cole¹ experimenting with *C. oryzae* and *C. granaria* showed that these insects remained alive for several days in moist air containing 80% of carbon dioxide, but that the pure dry gas was very fatal, acting either as a poison or as a desiccating agent or both. Cole regards moisture as the important factor.

Lefroy² considers that sun-dried wheat to which moisture does not get access is immune to insect attack provided it contains 7% of moisture or less.

¹ Cole. *Journal of Economic Biology*, I, 63—71.

² Private communication by letter, September 1912.

We shall show later that this opinion appears to be based upon insufficient information both biological and physical, since he refers only to *C. oryzae*.

The wheat harvest in the Punjab falls in the months of April and May, usually commencing about the middle of April. The harvest is threshed during the dry hot month of May when the temperature of the air is frequently higher than 115°F in the shade and 160°F by the black bulb thermometer in vacuo.

The following table shows the moisture contents of average samples of wheat harvested and threshed under ordinary country conditions at Lyallpur:—

TABLE XVII.

Showing the amount of moisture present in freshly harvested wheat in the Punjab (Lyallpur), June, 1914.

			HARD WHEAT	SOFT WHEAT
Moisture lost at 70°C.	{ in 4 days	...	2.03%	1.76%
	{ in 18 days	...	4.6%	3.4%
Moisture lost at 100°C.	{ in 1 day	...	8.7%	8.6%
	{ in 12 days	...	8.7%	8.8%

Such wheat as this then practically complies with the conditions suggested by Lefroy as requisite for immunity against insect attack. It might be thought that wheat takes up moisture in some quantity during the succeeding moist months of July and August, when the monsoon is in progress. To test this, samples of both hard and soft wheat were purchased from week to week during the season, in the Lyallpur market. These samples represent wheat grown in the preceding season, threshed in May, and stored either in the Lyallpur market or in the villages of the surrounding district. From the number of samples taken we may assume them to be truly representative of the stored grain found in this tract during the months of July to November. Tables XVIII and XIX show that the moisture content of the wheat has not advanced to any considerable extent over that of the recently harvested grain in May, the wheat still remaining in what we should ordinarily term a "dry" condition.

TABLE XVIII.

Showing the amount of moisture present in bazaar (Lyallpur) wheat during the months of July, August, September, October and November 1914.

Variety . . . Soft bazaar wheat.

Date of purchase of the sample	Date of experiment	MOISTURE % AT 70°C.			MOISTURE % AT 100°C.		
		Loss % in 24 hours	Further loss %	Total moisture %	Loss % in 24 hours	Further loss %	Total moisture %
2-7-1914	21-9-1914 to 8-10-1914	4.52	1.97	6.49	7.32	1.85	9.17
8-7-1914	Do.	5.92	1.50	7.42	8.32	1.42	9.74
13-7-1914	Do.	4.95	1.99	6.94	7.34	1.81	9.15
18-7-1914	Do.	6.05	1.50	7.55	8.37	1.55	10.92
28-7-1914	Do.	5.90	1.60	7.50	8.23	1.72	9.95
19-8-1914	Do.	5.91	1.70	7.61	7.99	2.03	10.02
29-8-1914	Do.	6.76	1.96	8.72	9.76	1.29	11.05
12-9-1914	Do.	5.32	2.00	7.32	8.02	1.81	9.83
15-9-1914	5-11-1914 to 25-11-1914	3.99	1.60	5.59	7.17	0.69	7.86
30-9-1914	2-12-1914 to 15-12-1914	4.89	2.58	7.47	8.41	0.79	9.20
7-10-1914	5-11-1914 to 25-11-1914	5.49	2.08	7.57	9.31	0.79	10.10
17-10-1914	Do.	6.17	1.90	8.07	9.25	0.86	10.11
23-10-1914	23-11-1914 to 15-12-1914	5.53	2.27	7.80	9.34	0.42	9.76
29-10-1914	Do.	5.97	2.18	8.15	9.88	0.16	10.04
7-11-1914	Do.	6.08	2.35	8.43	9.61	0.53	10.14
12-11-1914	Do.	5.87	2.10	7.97	9.48	0.54	10.02

TABLE XVIII—(continued).

Showing the amount of moisture present in bazaar (Lyallpur) wheat during the months of July, August, September, October and November 1914.

Variety . . . Soft bazaar wheat.

Date of purchase of the sample	Date of experiment	Germination value of fresh sample	GERMINATION VALUE AFTER HEATING THE SAMPLE AT 70°C.		GERMINATION VALUE AFTER HEATING THE SAMPLE AT 100°C.	
			For 24 hours	At the close of experiment	For 24 hours	At the close of experiment
2-7-1914	21-9-1914 to 8-10-1914	99	99	96	<i>Nil</i>	<i>Nil</i>
8-7-1914	Do.	100	96	98	<i>Nil</i>	<i>Nil</i>
13-7-1914	Do.	99	98	94	<i>Nil</i>	<i>Nil</i>
18-7-1914	Do.	92	94	86	<i>Nil</i>	<i>Nil</i>
28-7-1914	Do.	98	100	88	<i>Nil</i>	<i>Nil</i>
19-8-1914	Do.	96	93	96	<i>Nil</i>	<i>Nil</i>
29-8-1914	Do.	95	90	90	<i>Nil</i>	<i>Nil</i>
12-9-1914	Do.	98	99	89	<i>Nil</i>	<i>Nil</i>
15-9-1914	5-11-1914 to 25-11-1914	99	98	99	<i>Nil</i>	<i>Nil</i>
30-9-1914	2-12-1914 to 15-12-1914	98	92	92	<i>Nil</i>	<i>Nil</i>
7-10-1914	5-11-1914 to 25-11-1914	91	94	74	<i>Nil</i>	<i>Nil</i>
17-10-1914	Do.	89	93	86	<i>Nil</i>	<i>Nil</i>
23-10-1914	23-11-1914 to 15-12-1914	92	95	90	<i>Nil</i>	<i>Nil</i>
29-10-1914	Do.	75		80	<i>Nil</i>	<i>Nil</i>
7-11-1914	Do.	28	25	18	<i>Nil</i>	<i>Nil</i>
12-11-1914	Do.	75	72	45	<i>Nil</i>	<i>Nil</i>

TABLE XIX.

Showing the amount of moisture present in bazaar (Lyallpur) wheat during the months of July, August, September, October and November 1914.

Variety . . . Hard bazaar wheat.

Date of purchase of the sample	Date of experiment	MOISTURE % AT 70°C.			MOISTURE % AT 100°C.		
		Loss % in 24 hours	Further loss %	Total moisture %	Loss % in 24 hours	Further loss %	Total moisture%
2-7-1914	15-10-1914 to 29-10-1914	3.10	2.99	6.09	7.68	0.90	8.58
8-7-1914	Do.	2.78	2.83	5.61	7.08	1.09	8.17
13-7-1914	Do.	4.34	2.90	7.24	8.66	1.20	9.86
18-7-1914	Do.	3.60	2.85	6.45	7.64	1.02	8.66
28-7-1914	Do.	5.20	2.65	7.85	8.86	1.24	10.10
19-8-1914	Do.	4.24	2.82	7.06	8.25	1.10	9.35
29-8-1914	Do.	4.08	2.40	6.48	7.73	1.22	8.95
12-9-1914	Do.	5.16	2.72	7.88	9.22	1.30	10.52
15-9-1914	5-11-1914 to 25-11-1914	4.66	2.00	6.66	7.92	0.94	8.86
30-9-1914	Do.	4.46	1.36	5.82	7.40	0.93	8.33
7-10-1914	Do.	4.84	1.84	6.68	7.78	0.96	8.74
17-10-1914	Do.	5.20	1.86	7.06	8.85	0.91	9.76
23-10-1914	23-11-1914 to 15-12-1914	4.54	2.50	7.04	8.73	0.08	8.81
29-10-1914	Do.	6.15	1.90	8.05	9.96	0.66	10.62
7-11-1914	Do.	5.38	2.10	7.48	8.88	0.48	9.36
12-11-1914	Do.	5.63	2.72	8.35	9.48	0.48	9.96

TABLE XIX—(continued).

Showing the amount of moisture present in bazaar (Lyallpur) wheat during the months of July, August, September, October and November 1914.

Variety.....Hard bazaar wheat.

Date of purchase of the sample	Date of experiment	Germination value of fresh sample	GERMINATION VALUE AFTER HEATING SAMPLE AT 70°C.		GERMINATION VALUE AFTER HEATING SAMPLE AT 100°C.	
			After heating for 24 hours	At the close of experiment	After heating for 24 hours	At the close of experiment
2-7-1914	15-10-1914 to 29-10-1914	99	99	100	<i>Nil</i>	<i>Nil</i>
8-7-1914	Do.	99	99	98	<i>Nil</i>	<i>Nil</i>
13-7-1914	Do.	100	100	98	<i>Nil</i>	<i>Nil</i>
18-7-1914	Do.	99	99	97	<i>Nil</i>	<i>Nil</i>
28-7-1914	Do.	96	94	88	<i>Nil</i>	<i>Nil</i>
19-8-1914	Do.	88	82	82	<i>Nil</i>	<i>Nil</i>
29-8-1914	Do.	95	99	97	<i>Nil</i>	<i>Nil</i>
12-9-1914	Do.	96	87	92	<i>Nil</i>	<i>Nil</i>
15-9-1914	5-11-1914 to 25-11-1914	94	91	87	2	<i>Nil</i>
30-9-1914	Do.	99	100	96	10	<i>Nil</i>
7-10-1914	Do.	97	95	95	4	<i>Nil</i>
17-10-1914	Do.	100	98	88	<i>Nil</i>	<i>Nil</i>
28-10-1914	23-11-1914 to 15-12-1914	96	92	87	<i>Nil</i>	<i>Nil</i>
29-10-1914	Do.	99	100	97	<i>Nil</i>	<i>Nil</i>
7-11-1914	Do.	91	96	92	<i>Nil</i>	<i>Nil</i>
12-11-1914	Do.	93	94	92	<i>Nil</i>	<i>Nil</i>

The grain was hard and there was no sign of germination or mould. It appears questionable if wheat is capable of taking up moisture from a moist atmosphere under ordinary conditions of storage.

Physically speaking it consists of bad heat-conducting material and consequently it is unlikely to undergo the rapid temperature changes necessary to induce the condensation of moisture from a moist atmosphere, for low conductivity also means that it is a poor radiator of heat. During germination the grain appears to take up water only in the liquid state, for in experiments conducted by one of us to determine the amount of carbon dioxide given off during germination no germination took place unless the grain was in contact with a water film. In this way the grain is protected against germination under unsuitable conditions. The slight increase in moisture during the month of July and subsequent damp periods is probably surface moisture and insufficient to be taken up by the grain substances. This appears to be borne out by the figures of Tables XVII and XVIII which show that more moisture is lost at 70°C during the first twenty-four hours than is the case in the freshly harvested wheat.

The case is not the same as starch itself, though this is one of the principal ingredients of wheat, and notwithstanding that commercial starches are very hygroscopic and contain from 18% of water in the case of ordinary commercial starches¹ to 20·4% in the case of air-dried potato starch.²

In the wheat grain the starch is enclosed in a cellular envelope which evidently does not allow of the ready access or loss of moisture in the form of vapour. The same probably applies to the protein and other chemical contents of the endosperm. We conclude therefore that ordinarily speaking wheat is not a hygroscopic substance and cannot take up much more moisture than it contains at harvest time, the time when the wheat is at its driest and that "*moisture in the wheat*" is not the important factor in insect attack. Our results for the moisture content of wheat do not agree with those quoted by Fletcher.³ This author makes no mention of the conditions under which the moisture determinations were made.

2. EARLY EXPERIMENTS WITH CARBON DIOXIDE.

In selecting a germicide for use in India on such a common article of food as wheat, the range of chemical substances at our disposal is considerably narrowed by the cheap and ignorant labour which will be employed in its

¹ Wiley. *Agricultural Analysis*. Vol. III, p. 368.

² Davis and Daish. *Jour. Agri. Science*, Vol. VI, Part II, p. 165.

³ Fletcher, T. Bainbrigge. *Weevil and Dry Wheat*. *Agri. Jour. India*, Vol. VI, Part IV, October 1911, pp. 340—341.

application. Even in a large and modern wheat store like an elevator we in India cannot eliminate the Indian coolie and it is more than likely that the use of such substances as carbon disulphide, benzene, hydrocyanic acid, will raise the insurance rates to a prohibitive figure, for their use in this country would sooner or later be attended with serious accidents. The possibility of their use by the Indian villager in his granary is even more remote. We therefore differ from Lefroy when he says that carbon disulphide can be used in the new elevator to be erected at Lyallpur. In view of this and as Cole's results were by no means conclusive or exhaustive, it was thought advisable to test once more the effect of carbon dioxide, as this gas if it could be rendered effective would be cheap and easy of application and practically free from danger in an elevator. At the same time we decided to take records of its effect upon the germinating value of the grain.

Badcock¹ states that corn (*Zea Mays*) stored for thirty days in a sealed flask with carbon dioxide failed to germinate at the end of this period, so the process to be successful would have to be applied either for a sufficiently short period in the case of strong admixtures of carbon dioxide, or for longer periods for the gas in a more diluted form, but in all cases for such a time as will leave the germinating power unimpaired.

The gases of stored wheat and the effect of carbon dioxide on the germinating power of the grain. The amount of carbon dioxide given out by stored wheat.

Wheat like most seeds gives out carbon dioxide when in the dormant condition. Since the seed is dry during this period the carbon dioxide cannot result from the combustion of the carbohydrates of the endosperm, for these only become available as a food after the hydrolysing action of such enzymes as amylase and cytase which are only active after the grain is thoroughly moistened and at a suitable temperature. It must result therefore from the gradual decay or combustion of material in the embryo itself. This is borne out by the observation that in old stored grain the embryo is found to be much shrunk while the food materials of the endosperm are unimpaired. Indeed very often the grain has lost the power of germination by reason of this death of the embryo though it may still serve as a perfectly good food. As soon as germination sets in, the evolution of carbon dioxide rapidly increases through the combustion of a large portion of the carbohydrates of the endosperm.

The bins mentioned above were charged with wheat on 12th June 1911, and the air in one bin displaced with carbon dioxide on the 1st of August.

¹ Badcock. *Wisconsin Station Research Bull.* 22, pp. 87—181.

Samples of the bin gases were withdrawn on 4th April 1912, and their analysis gave the following figures :—

TABLE XX.

Analysis of gases from wheat bins, 1911-12.

Bin (A).		Bin (B).	
No carbon dioxide added		Carbon dioxide added	
Carbon dioxide per cent. in the bin gases	17.5	16.5	} Top Middle Bottom } of the bin.
	19.1	16.3	
	19.0	18.7	
	19.2	16.8	
Oxygen per cent. in the bin gases.	3.6	5.2	} Top Middle Bottom } of the bin.
	3.4	5.7	
	3.4	5.2	
	3.4	4.7	
Germinating power of a sample from the middle of the bin.	97%	4.3	Bottom
		93%	

On opening the bins and extracting the wheat, it was found that the grain in (A) had become wet through the monsoon rains having blown in under the edges of the roof, and as the bins had been constructed to be water-tight at the bottom and sides, this water could not drain away and was consequently absorbed by the wheat, inducing partial germination in about $1\frac{1}{2}$ feet of grain at the bottom.

The grain was mouldy and we account for the high percentage of carbon dioxide in this bin as derived from the germination of the grain, for in the following year the bins were again filled with wheat and the roofs reconstructed so as to render them waterproof against wind-driven rain and the following table shows the analysis of the gases obtained :—

TABLE XXI.

Showing the analysis of wheat bin gases, 1912-13.

Bin (A).		Bin (B).	
No carbon dioxide added		No carbon dioxide added	
Carbon dioxide per cent in the bin gases	{ 5.96 } bottom of the 5.84 } bin.	4.27 } half way down the 4.36 } bin.	
		4.58 } bottom of the bin. 4.64 }	
Germinating power	... 96%	93%	

The oxygen contents of these bins A and B in the 1911-12 experiment also show that in the case of A some 78% of the oxygen originally present in the bin gases has been "consumed" and in bin B not less than 71%. In 1912-13 unfortunately no record was taken of the amount of oxygen present at the end of the experiment. It appears from these figures that in a bin of 190 cubic feet capacity and a depth of eight feet the gases of the bin after the wheat has been stored for eleven months contain only 5.9% carbon dioxide

and in the shorter bin of greater capacity having a depth of $7\frac{1}{2}$ feet and 248 cubic feet capacity, only 4.5% of carbon dioxide. This carbon dioxide is produced as a result of the respiration of the stored grain and is probably derived entirely or almost entirely from the combustion of nutrient substances of the embryo itself.

We do not know at what rate carbon dioxide is respired by stored grain, it probably differs with temperature and moisture conditions, increasing as the temperature rises and as the amount of moisture and available oxygen increases. Whatever has been the rate of carbon dioxide production, the rate of diffusion has evidently been sufficient to lower the percentage of this gas to about 4% under the conditions of the above experiment.

In Table XX bin B was charged with carbon dioxide by a pipe entering the tank at the bottom, using a cylinder of compressed gas and admitting the gas from it into the bin slowly so as to displace the air above. In this manner we displaced the whole of the air. But at the end of eleven months the bin gases only contained about 16.5% carbon dioxide so that diffusion has evidently not proceeded further than this within eleven months. In bin A of the same year carbon dioxide production was proceeding at a fairly high rate long after the date on which B had been charged with this gas due to the accidental introduction of water and the consequent wetting and partial germination of the grain.

In taking samples of gases from the bins in the above experiments, small copper side tubes having a bore of $1\frac{1}{2}$ mm. were soldered into the bins during its construction. These were attached to a bulb filled with mercury and the gases drawn in by allowing the mercury to flow into a second bulb. By means of a three-way tap the first three or four samples collected could be rejected without disconnecting the apparatus so ensuring a representative sample of the gas.

Amount of carbon dioxide given out by germinating wheat.

To obtain some idea of the amount of carbon dioxide respired during germination the following experiment was made:—

Into a tube (18 cm. \times 4 cm.) were placed some glass beads, and 25 cc. of boiled and cooled water. Above the beads were placed 50 grams of wheat which had been washed with boiled and cooled water.

The tube was then stoppered with a rubber bung and completely immersed in the water of a constant temperature bath—at 32°C. Arrangements were made to admit pure air saturated with water vapour at laboratory temperature, the air being freed from carbon dioxide by soda lime and by

potash, and from spores, bacteria, etc., by passing through three Glover's towers packed with sterile cotton wool.

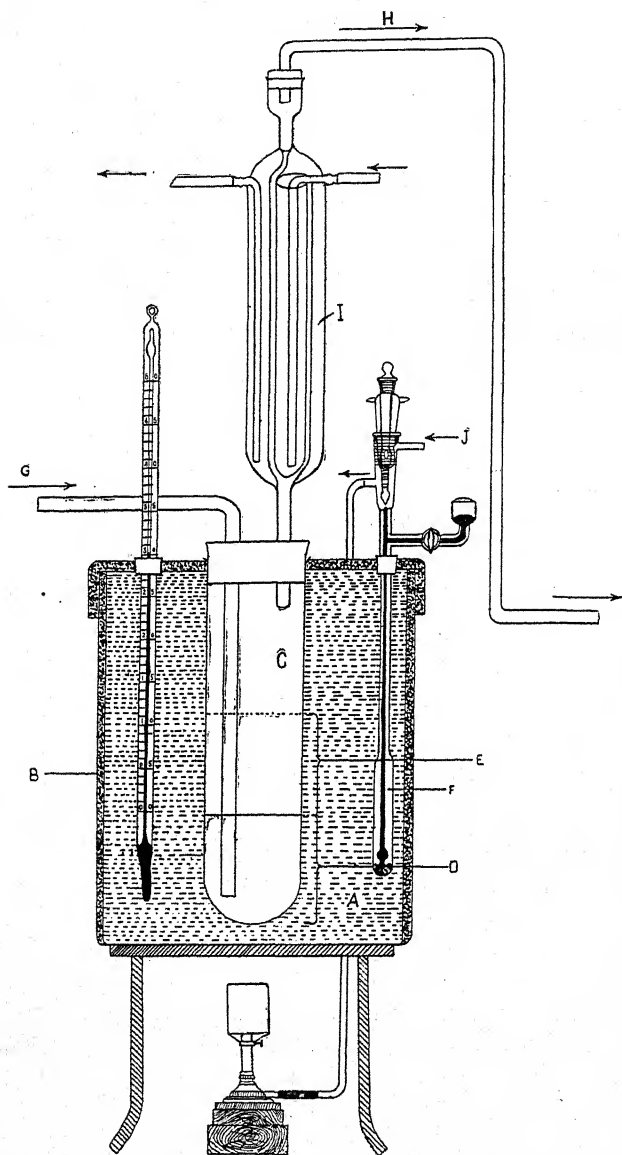


Fig. 2.

The gases issuing from the germination vessel pass upwards through a perpendicular condenser to ensure the return of any moisture tending to distil over from the tube when this is at a higher temperature than the laboratory.

Beyond this the gases are first dried and the carbon dioxide afterwards absorbed in potash bulbs and in soda lime tubes, using ordinary precautions.

Before commencing the experiment and after charging the tubes with wheat, this and the condenser were sterilized with chloroform vapour for 15 minutes—the vapour being afterwards removed by a rapid passage of sterile air. A similar experiment was made to determine the amount of carbon

dioxide generated by the germinating grain *without the passage of air*, that is,

supplying the wheat with only the air present in the tube and aspirating the carbon dioxide out into the absorption tubes at the end of the experiment.

TABLE XXII.

Showing the number of grams of carbon dioxide evolved during the germination of 100 grams of wheat at a temperature of 32°C.

TUBE A.—MOIST STERILE AIR ASPIRATED THROUGH THE APPARATUS DURING THE EXPERIMENT			TUBE B.—NO AIR ASPIRATED THROUGH DURING GERMINATION	
Date	Period of growth in days	Grams of carbon dioxide	Period of growth in days	Grams of carbon dioxide
7-4-11	0	0	1	0.08
10-4-11	3	2.5	3	0.8
11-4-11	4	3.06	4	1.76
12-4-11	5	3.28	5	2.4
13-4-11	6	3.52	6	2.8
14-4-11	7	4.14	7	2.9
15-4-11	8	4.70	8	2.96
16-4-11	9	5.34	9	2.99
17-4-11	10	5.91	10	3.02
27-4-11	20	10.92	20	3.5
4-5-11	30	15.54	30	3.88
15-5-11	41	19.00	40	3.98
24-5-11	50	19.60	50	4.02
2-6-11	62	20.44	70	4.09
10-6-11	70	21.90	130	4.22
17-6-11	77	22.54	...	...
29-6-11	89	25.34	...	...
8-7-11	99	27.32	...	...

A duplicate of this experiment gave 34 grams of CO₂ in 60 days from 100 grams of wheat.

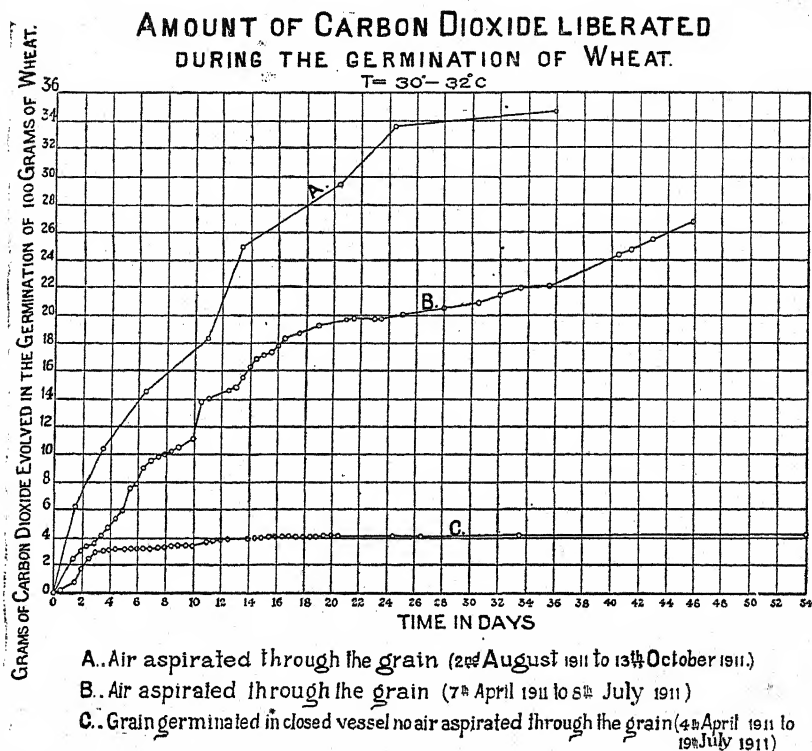
Figure 2 gives a sketch of the apparatus used and Table XXII and the curves in Fig. 3 (p. 220) show the results obtained.

From these tables it will be seen that when the grain is supplied with plenty of air the amount of carbon dioxide produced varies from 27 to 34% of the weight of the grain, and when no air beyond that contained in the germination tube is given, the amount of carbon dioxide produced is only 4.2%. At the end of the experiment the contents of the tubes A and B were examined.

A was found to contain a blackened mass of husks and shrivelled sprouts. B had sprouted but oxidation had not proceeded far enough to produce discoloration. These observations are of some interest and importance and might with advantage be repeated and extended. They provide a partial explanation of the results of the first bin experiment where we found a high carbonic acid content in the bin gases of that vessel to which water had gained admission; evidently there was a sufficiency of both air and water to admit of extensive germination of the grain at the bottom of the bin and a consequent

production of some quantity of carbonic acid. They show in a very marked manner the importance of allowing for adequate soil aeration during germina-

Fig. 3.



tion—a point of considerable importance in the farming of canal-irrigated lands in the Punjab where the presence of a fine clay in the canal water tends to produce an intensely hard surface crust of an almost cement-like nature.

Wheat was again stored in these bins during 1913-1914 and the top surface of the grain protected with eight inches of *bhusa* (the broken straw obtained by threshing the corn by means of bullocks treading out the grain on a prepared piece of hard ground). In all cases the grain used for these experiments was that grown on the Government Farm at Lyallpur, and threshed out by the above method. It was, however, cleaner on the whole than ordinary country wheat when introduced into the chambers. Early in September 1913 one of us examined the contents of these bins and found them to contain a number of specimens of the larva of *A. undulatus* and also *Tribolium castaneum*; of these, only the former is an active agent in damaging wheat. It is clear therefore that Lefroy's statement cannot be applied to the problem

in this province, since this opinion is based upon experiment with *C. oryzae* only, and as shown in Chapter IV the other insects, which damage wheat in the Punjab, do not behave in the same way towards moist and dry conditions as does *C. oryzae*.

Simultaneously with the first experiment in bins, we made some observations on the effect of carbon dioxide on the germinating power of wheat in weevil-infected samples.

Experiment. Since the introduction of grain into a bottle containing a mixture of air and carbon dioxide without disturbing the composition of the gas, presents almost insurmountable experimental difficulties, the following method was adopted. This method we consider gives a reliable comparative figure, for though the analysis of the gases at the end of the experiment does not represent the amount of carbon dioxide present in the gaseous mixture at the start but the sum of this gas present in the original mixture plus that derived from the respiration of the grain and any weevils present. Using the same quantity of grain for all experiments and making time and temperature conditions equal—these two latter factors will cancel out and give us the comparative effect of the carbon dioxide added at the commencement, on the germinating power of the grain and on the weevils if the grain contains them.

(A) 50 grams of good wheat, the germinating power of which was first determined, were placed in a wide-mouthed and stoppered bottle of 150 cc. capacity. Carbon dioxide gas from a Kipp's apparatus, well washed to free it from acid vapours, was then allowed to flow in by a tube reaching to the bottom of the bottle, the air of the bottle being displaced upwards. The amount of gas was regulated by counting the number of bubbles passing through the last wash bottle. 24 bottles containing wheat were taken and quantities of carbon dioxide corresponding to 28, 56, 85, 115, 170, and 240 bubbles of the gas were added, so as to obtain different quantities of the gas in each bottle.

The bottles were closed by well greased stoppers immediately after the addition of the carbon dioxide. Three months after, the gases of the bottles were extracted over mercury and analysed, and the grain tested for its germinating power.

Table XXIII gives the results obtained and confirms Badcock's¹ statement that the presence of carbon dioxide does affect the germinating power of grain. Badcock's experiment was made on maize and he found this grain stored for 30 days in a sealed flask charged with the gas failed to germinate at the end of that period.

¹ *Loc. cit.*

From our experiments there does not appear to be any numerical relationship between the loss in germinating power and the amount of the gas to which the grain has been subjected.

TABLE XXIII.

The effect of varying quantities of carbon dioxide on the germinating power of wheat.

1	2	3	4	5	6	7	8
Date of charging the bottle with grain and CO	Date of analysis	Number of bubbles of CO ₂ with which the bottle was charged	Quantity of wheat used	Bottle No.	Percentage of CO ₂ found on analysis	Germination value at end of experiment	Germination value of the grain before experiment
20-1-12	25-4-12	28	50 grams of wheat in all cases.	A ₁	9.7	35	97%
"	"	"		A ₂	10.2	24	
"	16-5-12	"		A ₃	4.2	51	
"	21-5-12	56		A ₄	2.4	45	
"	"	"		A ₅	4.2	40	
"	22-5-12	"		A ₆	3.9	35	
"	"	"		A ₇	19.2	35	
"	23-5-12	85		A ₈	19.5	39	
"	"	"		A ₉	21.3	35	
"	27-5-12	"		A ₁₀	20.6	40	
"	"	"		A ₁₁	6.1	35	
"	28-5-12	115		A ₁₂	6.9	35	
"	"	"		A ₁₃	23.06	39	
"	29-5-12	"		A ₁₄	22.6	35	
"	31-5-12	170		A ₁₅	11.0	31	
"	"	"		A ₁₆	10.4	33	
"	4-6-12	"		A ₁₇	20.5	38	
"	5-6-12	240		A ₁₈	20.7	43	
"	"	"		A ₁₉	5.7	80	
"	6-6-12	"		A ₂₀	5.9	81	
"	"	"		A ₂₁	22.2	79	
"	6-6-12	"		A ₂₂	21.9	40	
"	6-6-12	28		B ₁	12.4	38	
"	10-6-12	"		B ₂	12.8	55	
"	"	"		B ₃	14.6	63	
"	11-6-12	56		B ₄	14.2	52	
"	12-6-12	"		B ₅	15.9	60	
"	13-6-12	85		B ₆	15.0	38	
"	"	"		B ₇	11.8	52	
"	14-6-12	"		B ₈	11.6	52	
"	15-6-12	115		B ₉	14.2	52	
"	"	"		B ₁₀	14.8	52	
"	"	"		B ₁₁	10.9	52	
"	17-6-12	170		B ₁₂	10.9	52	
"	18-6-12	"		B ₁₃	14.2	52	
"	19-6-12	240		B ₁₄	18.4	52	
"	"	"		B ₁₅	18.6	52	
"	"	"		B ₁₆	17.0	52	
"	"	"		B ₁₇	17.6	52	
"	"	"		B ₁₈	31.0	52	
"	"	"		B ₁₉	30.8	52	
"	"	"		B ₂₀	28.7	52	
"	"	"		B ₂₁	28.9	52	

(B) A similar experiment was made on a mixture of weevil-infected and clean whole grain, a 50% mixture by weight.

Since the weevil-eaten grain is, however, lighter than undamaged wheat, and since the germination test is estimated by the number of grains germinating out of one hundred grains tested, it was necessary to estimate the number equivalent in a 50% mixture by weight; 20 grams of damaged and 20 grams of undamaged wheat were therefore counted and were found to contain the following number of grains of wheat.

<i>Number of grains of wheat in 20 grams weight.</i>	
Sound	Weevil infected
696	808

That is in 100 grams of a mixture of wheat containing 50 grams of sound wheat and 50 grams of weevilled wheat (50% of each) there will be by count 53% damaged grains.

TABLE XXIV gives the summarized results of this experiment. Several points are brought out in this table. In the first place the results of experiment (A) above are confirmed in showing a marked diminution in the germinating power of both sound wheat and weevil-damaged wheat after remaining in contact with carbon dioxide. In addition also no numerical relationship is established between the amount of gas and the decline in vitality except in the case of the weevilled grain where the vitality falls off as the percentage of carbon dioxide increases.

In this experiment four blank tests were made—two in which mixed wheat was placed in bottles the necks of which were closed with cotton wool (bottles C₁ and C₂) and two closed with glass stoppers but to none of these four was any carbon dioxide added.

Only the bottles C₁ and C₂ contained live weevils at the end of the experiment but all the tests showed an increase in the number of weevilled grains.

From this it appears that even in an atmosphere containing 50% of carbon dioxide the weevils had extended their ravages to fresh grain before succumbing to the effects of the gas.

Since writing the above note my attention has been directed to Kidd's¹ work on the controlling influence of carbon dioxide on the maturation, dormancy and germination of seeds.

¹ Kidd. *Proc. Royal Society*, 1914. B. 87, 408—421, 609—625.

TABLE

The effect of carbon dioxide on a mixture of sound and

1	2	3	4	5	6
Date of charging with CO ₂	Date of analysis	No. of CO ₂ bubbles with which the bottle was charged	Contents of the bottle	Number of the bottle	Description of the bottle
23-4-12.	20-6-12	<i>Nil</i>	53.7 % damaged grains (by count.)	C ₁	Bottle not closed, simply plugged with cotton wool.
"	"	"		"	"
"	21-6-12	"		C ₂	Bottle closed. No CO ₂ added.
"	"	"	20 grams good wheat (896 grains) together with 20 grams (cent per cent weight) weevil infected wheat (808 grains). (Total number of grains being about 1504).	"	"
"	22-6-12	32		C ₃	Bottle stoppered after charging.
"	"	"		"	"
"	24-6-12	64		C ₄	"
"	"	"		"	"
"	"	96		C ₅	"
"	"	"		"	"
"	25-6-12	160		C ₆	"
"	"	"		"	"
"	"	192		C ₇	"
"	"	"		"	"
"	26-6-12	256		C ₈	"
"	"	"		"	"
"	"	320		C ₉	"
"	"	"		"	"
"	27-6-12	960		C ₁₀	"
"	"	"		"	"

NOTE.—No weevils were found living on the date of analysis in any bottle.

XXIV.

weevilled wheat and on the weevils contained in it.

7	8	9	10	11	12	13
CO ₂ % absorbed by caustic potash	Germination % of good grains on the date of analysis	Germination % of weevilled grains on the date of analysis	Number of weevilled grains on the date of analysis	Number of good grains on the date of analysis	Germination % of good grains	Germination % of weevilled grains. (The wheat was cent per cent weevilled.)
0.14	62	28	898	633	...	...
0.18			59.7%	42.1%	...	...
17.84	82	81	972	585	...	...
17.55			64.6%	39.6%	...	...
20.18	45	15	905	600	...	...
20.12			60.2%	39.9%	...	...
23.00	75	17	900	676	98	24
23.05			59.8%	44.9%	...	...
25.53	55	5	991	661	...	...
25.27			65.9%	43.9%	...	...
29.94	39	Nil.	935	635	...	...
29.99			62.2%	42.9%	...	...
28.54	51	Nil.	945	665	...	...
28.30			62.8%	44.2%	...	...
35.75	71	1	938	709	...	...
35.72			62.4%	47.1%	...	...
30.64	89	2	990	475	...	...
30.62			65.8%	31.6%	...	...
50.97	85	3	804	596	...	...
50.58			63.5%	39.6%	...	...

except in the first bottle C₁ where 66 weevils were still living,

This author shows that the germination of seeds is retarded or inhibited by the high partial pressure of carbon dioxide. In seeds which failed to germinate on this account the germinating power was restored by removing the testa and in some cases by completely drying and rewetting. He attributes this loss of germinating power to the reduction in the permeability of the testa under the influence of carbon dioxide resulting in a reduced amount of oxygen reaching the embryo and a corresponding rise in the carbon dioxide pressure in the embryo tissues.

Experiments with Sulphur dioxide.

In compliance with the wishes of Government the effect of sulphur dioxide on grain was tested. In 1912, the proprietors of the Faridkot grain stores reported that sulphur dioxide had been successfully used there for fumigation purposes. Harcourt¹ had already studied the effect of hydrocyanic acid, carbon disulphide and sulphur dioxide on the baking properties of flour prepared from wheat subjected to the action of these gases.

Hydrocyanic acid did little damage to the bread-making properties of the flour. Carbon disulphide spoiled the flour for a time giving it a darker colour and Harcourt considered from his experiments that it would take upwards of five months exposure to air to restore the qualities of the flour after treatment with this substance.

Sulphur dioxide totally destroyed the flour for bread-making purposes. This we should expect from a knowledge of the properties of the gas. Sulphur dioxide is a powerful bleaching agent and owes this property to its affinity for oxygen, it being one of the most active reducing agents known to the chemist. It moreover forms an acid, sulphurous acid, when brought in contact with water, and in the presence of organic matter such as wheat flour and moisture, rapidly oxidises to sulphuric acid. Both of these acids will materially affect the nature of the carbohydrates present in flour changing them to sugars of an hygroscopic nature, and if much sulphuric acid be formed, a darkening in colour will succeed the first bleaching action of the sulphur dioxide. Our experiments did not aim at confirming or extending the enquiries of Harcourt on the effect of this gas on flour but were to prove the inapplicability of the gas owing to its injurious effects on the vitality of the grain—and the destruction of this for seed purposes.

¹ Harcourt. Effect of Fumigants on Flour. *North West Miller*, **83** (1910), No. II, pp. 661—662.

„ *Annual Report of Ontario Agricultural College*, **35** (1909), p. 66.

Experiment.

Three sets of experiments were done. In the first five all samples of wheat received the same amount of sulphur dioxide added to the air of the bottle—using the method described above in the case of carbon dioxide. The gaseous mixture was allowed to remain in contact with the grain for periods varying from 48 hours to 144 hours. In the second five samples all received different amounts of gas varying from 100 to 600 bubbles of the gas and allowed to act in all cases for a period of 24 hours. In the third set the method of the second was followed but much larger quantities of sulphur dioxide were added as will be seen from the analyses in Table XXV.

TABLE XXV.

The effect of sulphur dioxide on the germinating power of wheat. (50 grams in a bottle of 150 cc. capacity.)

Number of experiment	Gas (SO ₂) added for x seconds at the rate of 10 bubbles per second	Time during which the grain was exposed to the action of the gas	GERMINATING VALUE OF THE GRAIN		Amount of Sulphur dioxide and sulphurous acid calculated as SO ₂ present at end of experiment	REMARKS
			before treatment with SO ₂	after treatment with SO ₂		
1	20 seconds.	48 hours.	97%	30	1.40	Volumetric method of Analysis used. SO ₂ by Volume.
2	Do.	72 do.	Do.	27	1.05	
3	Do.	96 do.	Do.	23	0.75	
4	Do.	120 do.	Do.	24	0.75	
5	Do.	144 do.	Do.	21	0.53	
6	10 do.	24 do.	Do.	54	.23	
7	20 do.	Do.	Do.	49	0.53	
8	30 do.	Do.	Do.	45	0.91	
9	40 do.	Do.	Do.	38	...	
10	50 do.	Do.	Do.	26	1.05	
11	60 do.	Do.	Do.	23	2.30	Absorption method of analysis used. SO ₂ by Volume.
12	80 do.	Do.	Do.	97	Nil	
13	60 do.	Do.	Do.	97	Nil	
14	90 do.	Do.	Do.	65	Nil	
15	120 do.	Do.	Do.	36	1.30	
16	150 do.	Do.	Do.	32	3.60	
17	180 do.	Do.	Do.	38	11.96	

Two methods of analysis were followed, to check the amount of sulphur dioxide (or sulphurous acid) present at the end of the experiment. In the first dealing with small quantities of the gas, the contents of the bottle were agitated with boiled and cooled water, filtered, and a portion of the filtrate titrated with standard solution of iodine (decinormal). In the second, dealing with stronger mixtures, the gas was extracted from the bottle over mercury—and the amount of sulphur dioxide determined by absorption with dilute iodine solution in a Hempel's apparatus.

When the sulphur dioxide is as low as 0.23% by volume, and the time of exposure of the grain to this mixture only 24 hours, the vitality of this grain had fallen over 40%, thus showing the impossibility of treating seed wheat with this gas.

This closes what we may term the preliminary chemical enquiries on the subject and before further progress could be made it was necessary to examine the nature and habits of the various insect pests affecting wheat and generally referred to as "Weevils."

For this the services of Mr. A. J. Grove, Supernumerary Entomologist, were requisitioned and the results of his studies have already been given in Chapter I of this memoir. On these results have been based the experiments of Chapter III chemical experiments second series, Chapter V physical experiments connected with the effect of humidity—dryness—and heat on the weevils and Chapter VI remedial measures and experiments connected with these.

SUMMARY OF THE RESULTS OF THE EXPERIMENTS DESCRIBED IN CHAPTER II.

Briefly summarized these results are as follows :—

(a) The moisture content of Punjab wheat is not the same as described by Fletcher for wheat examined at Pusa, but on the other hand is shown to fulfil the conditions of immunity against weevil attack laid down by Lefroy and Fletcher.

Damage does, however, occur to stored wheat in this province in spite of this and we have shown elsewhere (Chapters I and V) that the other insects responsible for this *R. dominica* and *A. undulatus* do not react in the same way towards conditions of moisture and dryness as does *C. oryzae* the insect on which Lefroy's and Fletcher's opinion is based.

(b) Our experiments confirm Badcock's opinion that wheat stored in carbon dioxide loses its vitality.

(c) The injurious effects of carbon dioxide and sulphur dioxide on the vitality of the seed have been numerically defined and the impossibility of

using either of these gases as insecticides for wheat which is stored for seed purposes, shown.

(d) The amount of carbon dioxide expired by germinating wheat is shown to amount to as much as 35% of the total weight of the grain when this is supplied with sufficient oxygen to maintain the process of germination in full activity, and as low as 4% when the supply of oxygen is restricted.

(e) That wheat is not a hygroscopic substance like starch and does not take up moisture from a damp atmosphere such as exists during the monsoon period in the Punjab in July and August to a greater extent than one or two per cent., and that moisture so taken up probably lies on or in the outer shell of the grain since it is easily removed by drying at a temperature of 70°C.

(f) Sun-dried wheat at harvest time contains about 8% of moisture which can be driven off at 100°C. and from 3½ to 4½% of moisture which can be driven off at 70°C.

CHAPTER III.

CHEMICAL INVESTIGATIONS—2ND SERIES.

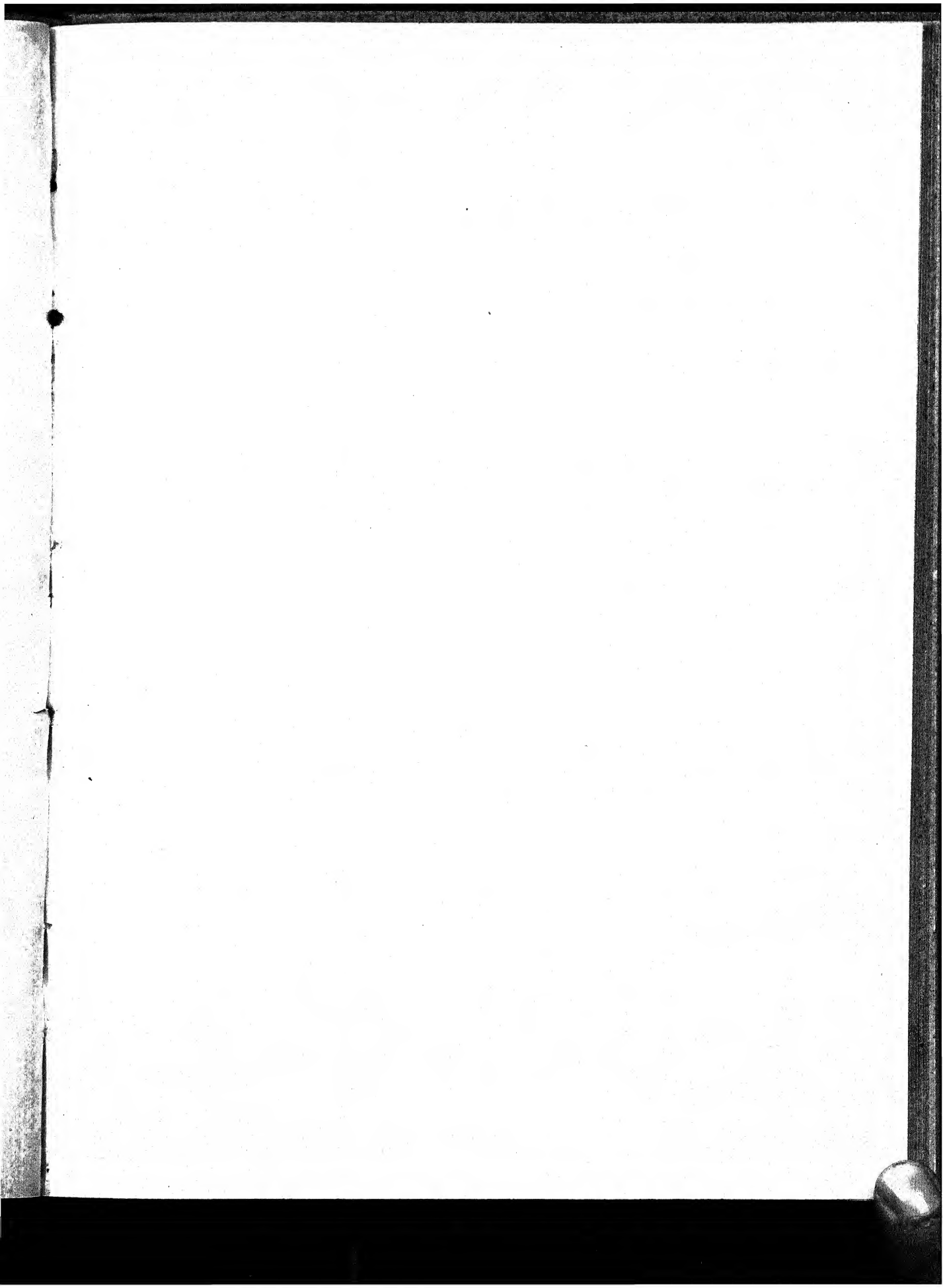
Effect of Carbon dioxide, Hydrogen and Nitrogen on weevils.

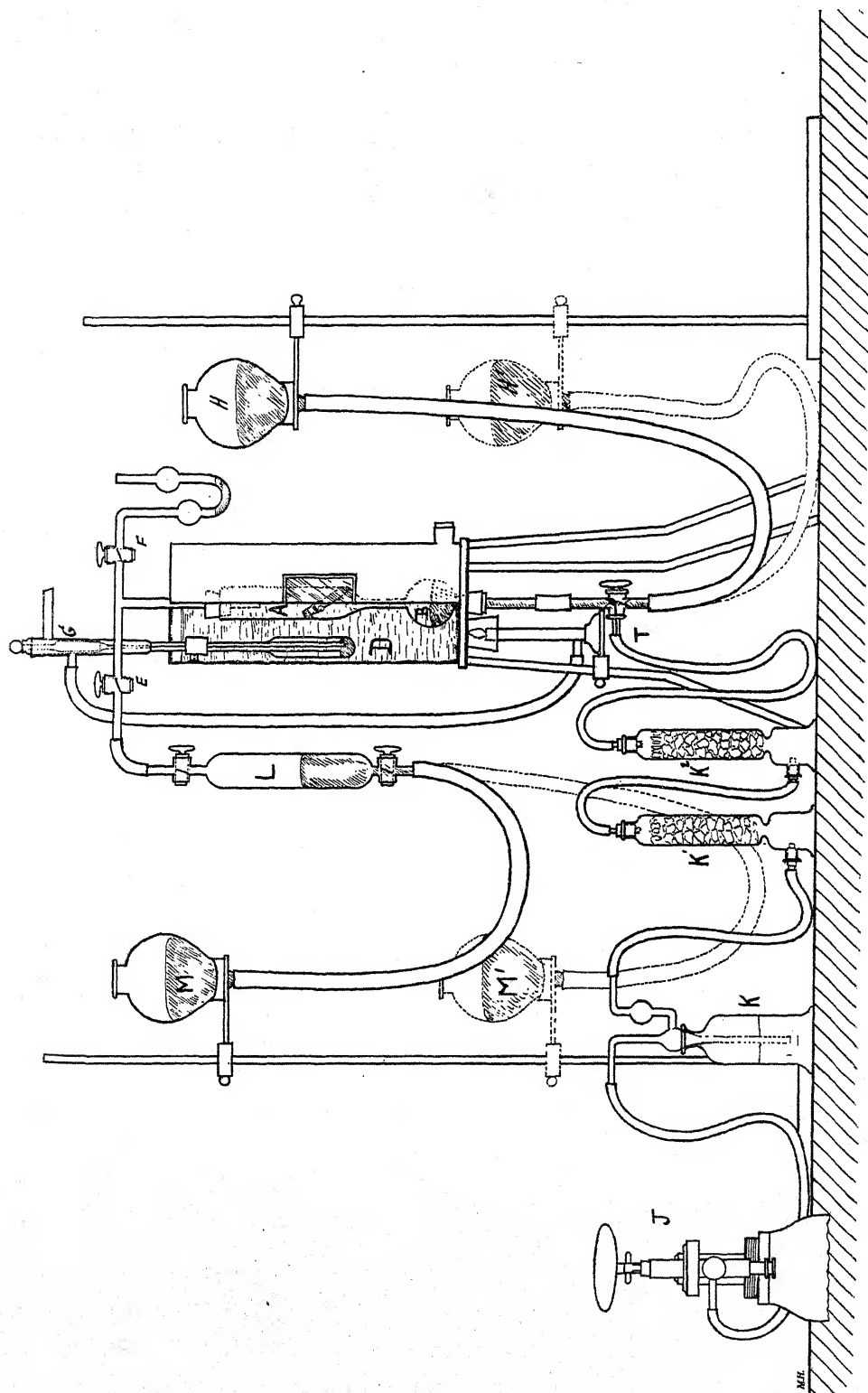
In February 1914, Mr. A. J. Grove was attached to the Punjab Agricultural staff to collaborate in the investigation and take up the entomological side of the enquiry in detail. Simultaneously with the study of the life-histories of the weevils detailed in Chapter I a more exact series of observations on the effect of gaseous insecticides was undertaken, confining ourselves in the first place to the gas carbon dioxide and working on the insects themselves. The three insects *Calandra oryzae*, *Attagenus undulatus* and *Rhizopertha dominica* were the subjects of this series of experiments, as observation proved these to be the insects most active in causing damage in the Punjab.

No systematic study of the process of respiration of insects from a chemical and physiological standpoint seems to have been undertaken by previous workers. Graham¹ concludes that respiration in insects follows the law of gaseous diffusion, but this seems based only on the fact that the aeration of tissues in insects is effected by means of a series of fine air tubes, trachæ, spreading to all parts of the body and having their openings in the form of spiracles on the sides of the body, and that these small openings and fine tubes offer the equivalent of the porous diaphragm of Graham's experiments in gaseous diffusion. Anatomical data as well as observations on the living animal, however, show that the opening and closing of these spiracles as well as the volume movement of the air tube is under muscular control, and biologists have been satisfied with this in the absence of further physical support of Graham's view, namely, that an exchange between the gases of the tube and the outer air is effected by means of muscular pressure.

Knowledge of the process seems to stop short at this reasonable explanation of gaseous exchange and no attempt has been made to examine the processes by which the insect makes use of the air thus brought in contact with its body tissues. The intake of air and the exhalation of carbon dioxide has been not unnaturally assumed, and the detailed study of the chemical processes

¹ *Researches*, p. 44.





Apparatus used in examining the effect of carbon dioxide, hydrogen and nitrogen on weevils.

of respiration left to the physiologist. This science has until very recent times been of interest only to students of medicine, its study has consequently been confined largely to the higher animals. These with their increased morphological differentiation of structure render the physiological problems more complex and more obscure and it is often in the study of simpler organisms that light is thrown on some process common to all. This has proved to be so in the present case. We shall deal with the experiments in the order in which they were made.

The first step taken was to examine Cole's results in detail, namely the effect of carbon dioxide on the three insects enumerated above, testing the effect of the gas at different temperatures and extending the experiments to other gases of a probable inert nature like nitrogen and hydrogen in order to test Graham's theory.

The apparatus used is shown in detail in Plate V. It consists of a glass incubating chamber A in which the insects are contained in small cages (C). These cages are only glass tubes closed at either end by wire gauze caps, and in them, the number (usually 10) of insects experimented upon are enclosed. The incubating chamber A is connected with a glass bulb B by means of a capillary tube. The object of this bulb is to provide space in the incubating chamber for the admission of mercury, to drive out some of the gases of the chamber for the purpose of analysis, without running any danger of interfering with the composition of these during the experiment. The volume of B is about 75 cc. while the volume of the tube A is about 150 cc. A and B are closed above by a rubber bung and below by a three-way tap T and at the upper end are in connection with a T-shaped capillary tube—one end of which has a small mercury manometer, which, by means of tap F allows the gas pressure in A and B to be reduced to atmospheric level, and the other side through which the gases can be withdrawn for analysis into the gas tube L for transfer to the gas analysis apparatus. The whole apparatus is in a constant temperature bath D, the temperature of which is regulated by the thermostat G.

Some difficulty was experienced in the use of mercury thread regulators of the type shown at G on account of the College gas supply being oil gas at high pressure (Mansfield's system) the working pressure of which is equivalent to 6" of water pressure on the gas holder. This was satisfactorily overcome by placing a 10-litre bottle containing some 6 inches of water in it, between the gas tap and G, and passing the gas through the water by a tube, the lower opening of which was 4" under water; this gave a gas pressure in the bottle

of $(6''-4'')=2''$ a satisfactory pressure to work the thermo-regulator and the small flames required for maintaining the bath at constant temperature.

In charging the apparatus the tube A B is first cleaned, dried and placed in position in the empty water bath. After the introduction of the cages C containing the insects, the T tube EF is attached to the tube A B with a rubber bung. The gas (carbon dioxide, etc.), the effect of which we wish to test, issues under its own pressure from a steel cylinder at J, and, after passing through the purifying vessels K, K_1 , K_2 enters the incubation chamber A B through the three-way tap T—the mercury reservoir H having first been lowered to the position H_1 to allow this. Gas is passed through for 15 to 20 minutes to entirely displace the air upwards (when filling the tube with hydrogen the gas enters at E and displaces the air downward through T which is then left open). After sufficient time has elapsed to displace the air, E is closed, and F opened, and a few bubbles of the gas passed through the manometer to clear that tube of air. B is then put in communication with H by turning T and the tube immediately above T filled with mercury. T is then closed and H_1 raised to H.

Lastly F is closed, and the water bath D filled with water at the temperature of the experiment. In order to check any change in the composition of the gases in A and B during the experiment, changes induced by the insects themselves if large enough to be detected by the analytical means at our disposal, or changes resulting from accidental leakage, the gas in A B is analysed after the last operation noted above, *viz.*:—the closing of the tap F—the time of the commencement of the gas treatment. The method of extracting and analysing the gases is simple. A gas tube L closed at either end with taps, and extending into capillary-bore tubes is attached to E by thick walled rubber tubing on the one side, and to a mercury vessel M on the other. L is first filled with mercury, and M is then lowered to M_1 , by slowly opening T mercury from H flows into B putting the gases of A B under pressure, and on opening E these flow into L—the first gas flowing into L from the tube outside E is rejected. After about 50 cc. of gas have been transferred to L, T is closed, leaving the gases in A B under a little more than atmospheric pressure, which latter is finally reduced to atmospheric pressure by opening F. Before doing so however the capillary tube outside E is filled with mercury by first closing the upper tap of L and forcing mercury in to put the gas in L under pressure. The lower tap of L is then closed and the tube inverted. On opening the upper tap, mercury from L now flows into E—all taps are now closed and L is disconnected and removed to the gas analysis apparatus and the sample introduced and analysed in the usual manner.

The apparatus used in these experiments for the analysis of the gases was first Bone's modification of Frankland's apparatus, but experience showed the accuracy of this method of working was really beyond that required. In view of the tediousness of the method we subsequently substituted Macfarlane and Cadwell's modification of Sodeau's apparatus.¹

After the lapse of some hours the gases of the tube A B were again analysed and the apparatus opened to examine the insects and determine the number which had been killed. The first effect of carbon dioxide was to induce intense activity in the insects for the period of a few seconds, after which they became inert and without motion. It was found however that this was not death, for on restoring them to an air atmosphere they recovered. We determined the *time*, *temperature* and *gas concentration* necessary to produce death and the time so taken to kill the insects we have called the *lethal period*. To determine this lethal period it was necessary to make many experiments before the exact period could be arrived at, and in the case of carbon dioxide at a temperature of 35°C, upwards of 60 experiments on each insect and 120 analyses of the tube gases were required before the lethal period was determined. As some of the test periods were upwards of 60 hours it will be seen how lengthy and tedious was the method of investigation, for in the table which follows only one figure appears for all these analyses and tests.

The following table XXVI shows the method of recording the result of one test on the three insects.

Duplicate tubes of each insect were taken—each tube containing 10 insects and the number given in column 5 shows the number *recovering*. The difference between this number and 10 will be the number of insects killed.

TABLE XXVI.

Example of the method of investigating the effect of carbon dioxide on the insects Attagenus undulatus and Calandra oryzae.

Date	Analyses of the gas before and after CO ₂ %		Number of hours of treatment	Number of insects recovering	Types
	Before	After			
1-9-14	99.8	99.78	11 hours	0 1	} <i>A. undulatus</i> .
	99.92	99.89	10½ "	7 3	
	99.96	99.93	10 "	2 2	
21-11-14	99.5	99.5	2½ "	0 0	} <i>C. oryzae</i> .
	98.4	98.4	3 "	0 1	
	98.3	98.3	4 "	0 0	

¹ J. C. S. I. Feb. 28, 1903, p. 187.

TABLE XXVII.

Showing the Lethal period for *Attagenus undulatus*, *Calandra oryzae* and *Rhizopertha dominica* in an atmosphere of dry carbon dioxide.

TEMPERATURE	ATTAGENUS UNDULATUS.				CALANDRA ORYZÆ.				RHIZOPERTHA DOMINICA.			
	ANALYSIS OF GAS		Lethal period in hours	Density of gas (air at 0°C=1)	ANALYSIS OF GAS		Lethal period in hours	Density of gas (air at 0°C=1)	ANALYSIS OF GAS		Lethal period in hours	Density of gas (air at 0°C=1)
30°C	89	1.3720	98.8	98.8	30	1.3718	98.60	99.00	14	1.3720
30°C	63½	1.3786	99.7	100	51½	1.3770	99.80	99.70	50	1.3788
35°C	37	1.3459	98.9	98.2	17	1.3459	99.56	99.19	22	1.3529
40°C	12½	1.3324	98.1	98.1	3½	1.3256	99.70	99.42	7	1.3326

TABLE XXVIII.

Showing the Lethal period for *Attagenus undulatus*, *Calandra oryzae* and *Rhizopertha dominica* in dry hydrogen.

TEMPERATURE	ATTAGENUS UNDULATUS.				CALANDRA ORYZÆ				RHIZOPERTHA DOMINICA.			
	ANALYSIS OF GAS		Lethal period in hours	Density of gas (air at 0°C=1)	ANALYSIS OF GAS		Lethal period in hours	Density of gas (air at 0°C=1)	ANALYSIS OF GAS		Lethal period in hours	Density of gas (air at 0°C=1)
30°C	95.8	95.9	28	.09599	96.3	96.10	27	.09275	95.75	94.7	16	.0973
35°C	96.5	96.4	22	.09061	90.3	90.09	11	.13925	90.10	89.8	14	.14083
40°C	95.3	96.1	16	.09133	96.1	96.10	2	.09133	96.10	96.1	4	.09133

TABLE XXIX.

Showing the Lethal period for *Attagenus undulatus*, *Calandra oryzae* and *Rhizopertha dominica* in dry nitrogen.

TEMPERATURE	ATTAGENUS UNDULATUS.				CALANDRA ORYZÆ.				RHIZOPERTHA DOMINICA.			
	ANALYSIS OF GAS		Lethal period in hours	Density of gas (air at 0°C=1)	ANALYSIS OF GAS		Lethal period in hours	Density of gas (air at 0°C=1)	ANALYSIS OF GAS		Lethal period in hours	Density of gas (air at 0°C=1)
	At beginning	At end			At beginning	At end			At beginning	At end		
30°C	100	100	55	·8764	99·9	99·8	28	·8764	99·6	99·7	31	·8764
30°C	98·8	100·1	20½	·8764	100·8	99·5	17	·8764	99·7	99·4	16	·8764
35°C	99·6	99·0	30	·8620	99·7	99·6	11	·8620	99·6	99·7	16	·8620
40°C	99·9	100	13	·8484	100	100	4	·8484	99·0	99·7	6	·8484

In all these experiments dry gases were used. The time at our disposal did not allow of our investigating the lethal period for the same gases in a moist condition. We investigated the effect of dry and moist air however and this will be described in Chapter V. The results are shown in tabular form for the three gases carbon dioxide, hydrogen and nitrogen in Tables XXVII, XXVIII and XXIX.

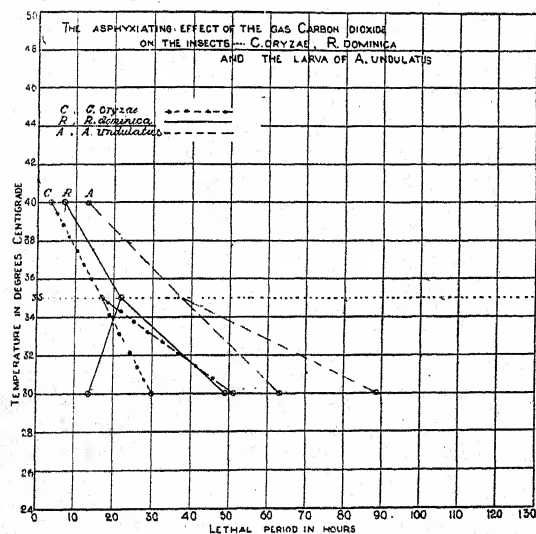


Fig. 4

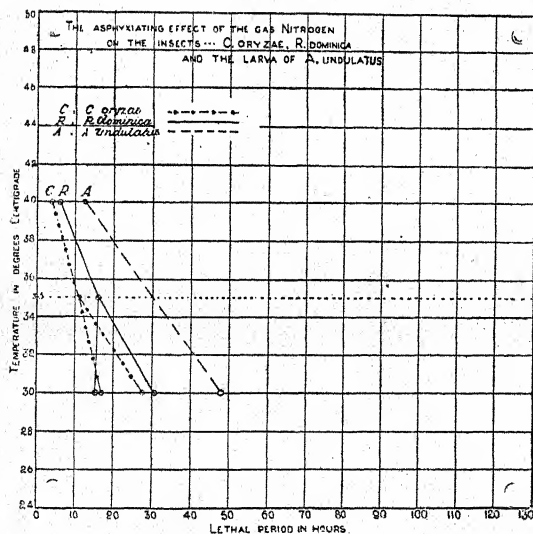


Fig. 6.

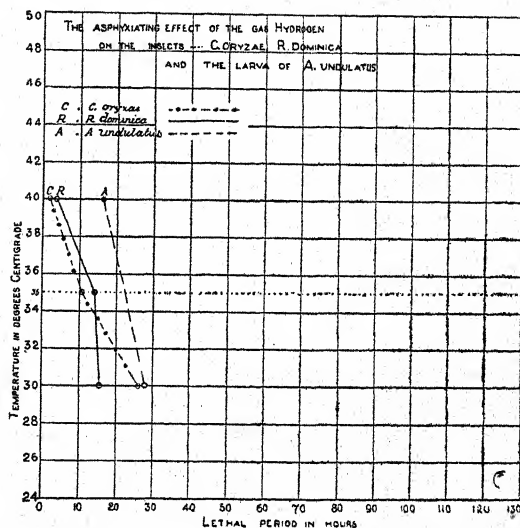
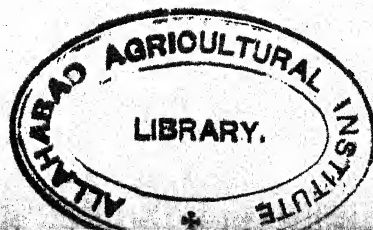


Fig. 5.

Several points are brought out in these tables. The first is the wide discrepancy between the recorded duplicates which were done at a different season of the year. This shows that the effect of these gases on the insects differs very considerably at different times of the year—it is not *temperature* here that matters, or the composition of the gas—it is the *condition of the insect*; we shall refer to the point in more detail later. The second point brought out in the results is the general shortening of the lethal period as the temperature rises—this is most marked in the case of *A. undulatus* with carbon dioxide.



Thirdly, *A. undulatus* seems to be more resistant to all these gases than *R. dominica* and *R. dominica* more resistant than *C. oryzae*.

Fourthly, the lethal period is much shorter in all cases as the density of the gas applied decreases. On first sight this latter seems to give support to Graham's theory that the respiration of these insects follows the law of gaseous diffusion.

The figures were therefore closely examined as follows:—

The following table gives the density of these gases at 0°, 30°, 35° and 40°C. as compared with air at 0°C:—

TABLE XXX.

Density of air, hydrogen, nitrogen and carbon dioxide compared with air, density=1 at 0°C.

Gas	T=0°C	T=30°C	T=35°C	T=40°C
Air	1.0	0.90120	0.8863	0.87240
Carbon dioxide	1.52900	1.37700	1.3550	1.33400
Hydrogen	0.06949	0.06263	0.0616	0.06063
Nitrogen	0.97240	0.87640	0.8620	0.84840

From these figures and a knowledge of the composition of the gas in the tube, we can calculate the density of the gas actually present in the tube during the experiment. For example in the case of *Attagenus undulatus* at 30°C. the analysis of the gas was hydrogen 95.9—nitrogen 4.1.

The density of this mixture would therefore be

$$\frac{(95.9 \times .06263) + (4.1 \times .8764)}{100} = 0.09599$$

If the lethal period is related to the rate of diffusion then according to Graham's law the following relation should hold:—

$$\frac{\text{Lethal period in carbon dioxide}}{\text{Lethal period in hydrogen}} \propto \sqrt{\frac{\text{Density of hydrogen}}{\text{Density of carbon dioxide}}}$$

$$\text{Since } \frac{\text{Velocity of diffusion of carbon dioxide}}{\text{Velocity of diffusion of hydrogen}} = \sqrt{\frac{\text{Density of hydrogen}}{\text{Density of carbon dioxide}}}$$

Example.—Comparison of the lethal periods for *Attagenus undulatus* at 30°C. with the diffusion ratios of the gases in which the lethal period was determined, and calculated from the densities of the gases.

$$\text{By analysis } \left\{ \begin{array}{ll} \text{Density of carbon dioxide at 30°} & \dots 1.3459 \\ \text{Density of hydrogen at 30°} & \dots 0.0896 \\ \text{Density of nitrogen at 30°} & \dots 0.8620 \end{array} \right.$$

$$\frac{\text{Velocity of diffusion of carbon dioxide}}{\text{Velocity of diffusion of hydrogen}} = \sqrt{\frac{0.0896}{1.3459}} = 0.2583$$

$$\frac{\text{Velocity of diffusion of carbon dioxide}}{\text{Velocity of diffusion of nitrogen}} = \sqrt{\frac{0.892}{1.3459}} = 0.80113$$

$$\frac{\text{Velocity of diffusion of hydrogen}}{\text{Velocity of diffusion of nitrogen}} = \sqrt{\frac{0.862}{0.896}} = 0.3102$$

The reciprocals of these velocity diffusion ratios are :—

0.2583	reciprocal	3.87
0.80113	reciprocal	1.24
0.3102	reciprocal	3.22

The lethal periods in the same experiment were as follows :—

Carbon dioxide.		Hydrogen.		Nitrogen.
37 hours.		22 hours.		30 hours.
Ratio $\frac{\text{CO}_2}{\text{H}}$	=	$\frac{37}{22}$	=	1.7
$\frac{\text{CO}_2}{\text{N}}$	=	$\frac{37}{30}$	=	1.23
$\frac{\text{H}}{\text{N}}$	=	$\frac{22}{30}$	=	0.73

After a similar examination of all the results of Tables XXVII, XXVIII and XXIX we are unable to obtain any support of Graham's theory that the respiration of insects is regulated by the laws of gaseous diffusion.

The velocity ratios calculated from the gas analysis figures show that temperature will have but little effect on this *comparative* value, since for the small increase in temperature covered by the range of our experiments the small difference in the mass of the reacting gas molecules will have but a slight effect on the kinetic energy of the molecule, both gases being heated through the same range of temperature.

TABLE XXXI.

Diffusion velocity ratios calculated from the composition of the gases used to test the lethal period for Attagenus undulatus.

	VELOCITY OF CO ₂ VELOCITY H.	VELOCITY OF CO ₂ VELOCITY N.	VELOCITY OF N. VELOCITY H.
30°C	0.2641	0.798	0.302
35°C	0.2583	0.80113	0.3102
40°C	0.2628	0.798	0.305

If then the composition of the gases used in these experiments is so constant that the diffusion ratios remain as close as is shown in the table, the lethal period ought to show a like similarity *if the exchange of gases through the spiracles and air tubes of the insect follows the law of gaseous diffusion*. Even if there are two or more factors making up the lethal effect—and it is difficult to conceive such inert gases as nitrogen, hydrogen and carbon dioxide acting otherwise than as asphyxiating agents, this diffusion factor will at least remain constant.

The only deduction we are able to draw however is that the lethal effect increases with the temperature and that the effect therefore is in all probability of the nature of a chemical reaction. This view seems to receive support in the wide variation observed in the case of the gas carbon dioxide which in the first series of experiments made at 30°C. gave a lethal period of 89 hours. This latter result was obtained in an experiment conducted in the month of March, while the period of 65 hours was determined in the following autumn.

CHAPTER IV.

RESPIRATION.

Historical. The experiments detailed in Chapter III have yielded results so incomprehensible, and so incapable of interpretation, that further enquiry was made into the possibility of these gases entering into, or interfering with, some cycle of chemical changes—normally taking place in the process of animal oxidation or respiration. It seems very unlikely that the gases themselves have taken part in any of the reactions connected with this process, since no alteration in the composition of the gas was detectable in the course of the experiment. On the other hand it must be conceded that the amount of gas brought into play by the number of insects experimented on, is probably so small compared with the total amount of gas present in the incubation tube, that the analytical methods at our disposal were too crude to detect the minute change, if any, which had taken place.

In order to find a satisfactory explanation we therefore turned to an examination of the process of respiration and more especially respiration in the cell as a unit of the entire organism. Historically Lavoisier was the first to recognize the importance of oxygen in the life process, and he outlined the part played by this substance in the combustion processes taking place in animals. Lavoisier believed the lungs to be the seat of the oxidation processes taking place in the animal organism. This was not feasible because the energy so set free would not be available for the tissues of the body, and the cells comprising them. Magnus,¹ by analyses of the blood, and the gases of the blood, showed this to contain oxygen until the final capillaries were reached when it disappeared. He thus proved that all animal oxidation did not take place in the lungs but his researches left undecided whether the oxidation took place in the blood itself, or whether the oxygen passed through the wall of the blood vessels into the tissues. Ludwig and Schmidt² imagined that the tissues were constantly giving up oxidisable substances to the blood, and in support of this showed that the restriction of an animal's supply of oxygen led to

¹ Magnus. *Ann. Physik*, **40**, 583. 1837.

" " " **64**, 177. 1845.

² Ludwig and Schmidt. *Ber. über die Verhandl. der Sächs. Ges. Wissen. Leipzig. Math. Physikal. Klasse*, **19**, 99. 1867.

suffocation; that the blood of such suffocated animals contained but traces of oxygen, and that on exposing the blood to the air or oxygen, the latter disappears, and the amount of carbon dioxide in the blood increases. They considered that in a suffocated animal these oxidisable substances given up to the blood by the tissues, accumulated.

We now know that blood contains cells, the red and white corpuscles, which themselves undergo metabolism, and thereby very easily consume oxygen and give out carbon dioxide. Afonassiew¹ then showed that only the blood corpuscles, and not the serum of a suffocated animal, could thus take up oxygen. The assumption that the combustion takes place in the tissues and cells of the tissues, was proved by Pflüger and Oertmann² in the following manner. A frog's blood was removed and replaced with normal saline solution. The animal was then placed in an atmosphere of pure oxygen, and consumed as much of the gas and evolved as much carbon dioxide as a normal frog.

To-day there is no doubt that oxygen diffuses into the tissues, and that the cells themselves derive their energy by the combustion of nutrient substances in them. One of the principal proofs of this is, that the blood itself possesses no oxidising properties.³ For example, salts of lactic acid placed in the blood remain unchanged whereas in their passage through the organism they are completely and rapidly oxidised. This is the more convincing when carried out on surviving organs. If for example blood is conducted through the liver of a dead animal by the portal vein, it can be shown that ammonium formate introduced into the blood, disappears, and in its place urea is formed.⁴ This is not the case if the ammonium formate is brought only in contact with the blood. Contact with the liver cells is essential.

That oxygen actually passes through the walls of the blood vessels is strikingly shown by the way the foetus is provided with this element. It is well known that there is no direct connection between the vascular system of the mother and of the child. The circulation of the foetus is isolated.⁵ Bancroft⁶

¹ Afonassiew. *Ber. über die Verhandl. der Sächs. Ges. Wissen. Leipzig. Math-Physikal Klasse*, **24**, 253. 1872.

² Pflüger and Oertmann. *Pflüger's Arch.* **15**, 382. 1877.

" " " " " **10**, 251. 1875.

³ Pflüger. *Pflüger's Arch.* **6**, 43. 1872.

Hoppe-Seyler. " " **7**, 407. 1873.

⁴ Abderhalden. *Text-book of Physiological Chemistry*, translated by Hall. Wiley and Sons, New York (1908).

⁵ Pflüger. *Pflüger's Arch.* **1**, 686. 1868.

Külz. *Zeit. Biolog.* **23**, 321. 1887.

⁶ Bancroft. *Biochem. Jour.* **I. I.**, 1906.

has shown that saliva contains 0.5% of oxygen by volume, which could only have come from the circulation by diffusion.

All this gains further support when we come to examine the system by which the lower organisms receive their oxygen supply in a direct form. In insects there is a modified vascular system and the oxygen reaches the tissues in the gaseous form through an infinitely branched tracheal system.

While all these observations tend to show that the higher organisms are capable of taking up and directly using the oxygen of the air, quite a separate series tend to show that they can obtain energy from certain hydrolytic cleavage processes. It is known that intestinal parasites live apart from an oxygen containing atmosphere and even frogs can for a time¹ live without oxygen and produce carbon dioxide. Though this is possible we know that the energy derived from such cleavage processes is insufficient for the production of energy required for the animal processes. Fick and Wislicenus² proved this in an interesting series of experiments on themselves in mountain climbing. If the animal cell is capable therefore of existing on the energy derived from cleavage processes, as well as utilizing atmospheric oxygen for the oxidation processes when an additional expenditure of energy demands the more rapid combustion of the cell nutrients, it follows that the cell is a facultative anaerobe. Here we find a parallel in the unicellular organisms, where there exist not only bacteria which demand the presence of oxygen, or can exist in its absence (aerobic and facultative anaerobic bacteria), but others, the anaerobic bacteria to which oxygen acts either as a deterrent or even as a poison. It is a characteristic function of all bacteria that they evolve carbon dioxide whether they take up oxygen from the air or not. Exception.—The acid forming bacteria—the vinegar bacteria—may evolve no carbon dioxide when oxidising an abundance of alcohol to acetic acid. The bacteria which are anaerobic or temporarily so, must derive their oxygen from the nutrient material on which they subsist or to put it more exactly they derive the energy necessary for the vital processes from the partial decomposition of chemical substances rich in oxygen. Examples, decomposition of grape sugar by the *Saccharomyces*, the reduction of nitrates in the presence of organic matter by anaerobic bacteria.

We are not further concerned here with the exact function of the blood corpuscles, or the serum in which they exist. It is sufficient for our purposes in

¹ Pflüger and Oertmann. *Pflüger's Arch.* **15**, 382. 1877.

" " " " " **10**, 251. 1875.

² Fick and Wislicenus. *Vierteljahresschrift des Züricher naturforschenden Gesellsch.*, **10**, 317. 1865.

this research to note in passing that in the higher animals, these serve the purpose of conserving an oxygen supply through its absorption by hæmoglobin, and that the gas then passes *via* the blood plasma, and diffusion into the tissues of the body and the cells comprising them.

So far then we establish a parallel between the cells of all organized structures, either animal or vegetable, namely, that the oxygen of respiration reacts in the tissues in solution dissolved in the cell plasma. Whether it reaches the individual cell in the gaseous form as in the insects with their highly branched tracheal system, or through the medium of a loose chemical combination such as oxyhæmoglobin and from this *via* the blood plasma does not concern us here. We have now to examine the conditions under which the oxygen in solution in the cell can perform this process of oxidation, which as we have seen above in the oxidation of ammonium formate can be effected by the liver cells but not by the blood, though this latter is infinitely richer in oxygen than the former. (For a full historical account of this process of blood aeration see Abderhalden's *Physiological Chemistry*, 1908, London, Chapman and Hall, Chapter XVIII.)

If we expose such substances as fats, albumins, and carbohydrates, which normally constitute the "nutrient" material of the cell, to the action of oxygen at body temperature, no perceptible oxidation of these materials takes place. On the other hand within the body itself they are rapidly oxidised with the production of carbon dioxide, urea, and water. Consequently conditions must prevail within the cell which facilitate the action of oxygen upon the material exposed to its action.

We are acquainted with a number of facts which prove that even within the animal tissues oxygen as such is unable to act upon unchanged food. We know that in the process of respiration it is the food fuel which is consumed and not the cell substance. Under certain conditions (disease) the body may lose the power to deal with certain food substances such as carbohydrates. In diabetes, substances hard to oxidise are as easily consumed as when the body is in a healthy condition. Only unchanged dextro-glucose has ceased to act as a food, because the organism has lost the power to utilize it.

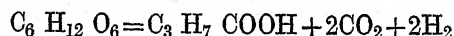
If grape sugar is but slightly changed before its introduction, the diabetic tissue is then able to deal with it.

If animal oxidation took place merely as a result of the coming together of oxygen and nutrient, then an increased supply of oxygen should be followed by a more vigorous oxidation, but this is not the case. Under normal conditions it is not possible to increase the amount of oxidation taking place in the tissues by increasing the amount of oxygen given to the animal.

The fact that oxygen in the condition in which it exists in the tissues is incapable of consuming the unchanged nutrient, enables the cell to adjust its metabolism to its requirements, above all it enables the cell to utilize certain and particular materials to suit its requirements.

Up to this point, no clear explanation as to the nature of animal oxidation processes has been put forward. We have recognized only the initial materials food and oxygen, and the final products of the combustion, carbon dioxide, water and certain nitrogen-containing substances such as urea.

The following hypotheses have been formulated. It has been suggested that the oxygen has been changed in form so that it more readily attacks the nutrient. Schönbein¹ attributes the numerous oxidations taking place in the plant organism to the primary formation of this changed oxygen from ozonizing material present in the plant. This assumption breaks down for want of experimental proof of the presence of ozone in the plant cell, and from the fact that small amounts of this substance are poisonous to the cell protoplasm. Hoppe-Seyler² assumed the presence of active oxygen in tissue and based his assumption on the fact that in animal tissues energetic reduction takes place side by side with oxidation. In this way reducing substances are formed which unite with one atom of the oxygen molecule, setting the other atom free. The butyric fermentation of glucose is an example of such a reduction.



The assumption receives support in the theory of nitrification in which we assume that the organism responsible for nitrification first produces readily oxidisable substances which then decompose the atmospheric oxygen molecule and thus form nascent (active) oxygen for the oxidation of nitrogen.

If we are to believe that oxidation in the animal substance takes place in this way we must assume first of all that the food substances are hydrolyzed, and that easily oxidisable substances are then formed which are oxidised by the oxygen received in the tissues from the blood and *at the same time part of the oxygen is rendered nascent.*

The theory breaks down for want of experimental proof. We could understand why the diabetes cannot oxidize (*d*) glucose by assuming the absence of the necessary hydrolyzing ferment for the sugar, but we cannot understand why the nascent oxygen produced from the oxidation of the other food substances is unable to act on the sugar.

¹ Schönbein. *Poggendorf's Annalen.* 65, 171. 1845.

² Hoppe-Seyler. *Pflüger's Arch.* 12, 16. 1876.

There are certainly present in the cell a number of ferments which are specific—that is to say, induce chemical reaction according to the class of compounds on which they react, and if we assume that the cells do not contain these ferments in an active condition but become active under such conditions as the cell economy may demand, we can understand how the cell may contain food, ferment and oxygen without any oxidation taking place. The cell consumes the cleavage products of the food it obtains, such as the decomposition products of albumin, glycocol alanin, etc.,—oxidising these to urea. But this is only true of substances having the same molecular structure and configuration—thus a rabbit fed with *d.l.* leucine oxidises only the *l.* leucine, the other half of the racemic molecule *d.* leucine appearing unchanged in the urine. This is because the cells contain no ferment capable of dealing with *d.* leucine and so it remains unoxidised. (cf. Abderhalden's *Text-Book, Physiological Chemistry*, p. 443).

In the absence of sufficient oxygen we should expect to get an accumulation of fermented and readily oxidisable substances in the cell, particularly as the entire energy of the animal depends on that set free in hydrolytic decomposition.

Bunge¹ has shown that ascarids can exist several days without any oxygen supply, and we have already quoted Pfüger's experiments with frogs. In such cases as these we should expect to find some evidence of such easily oxidised substance as hydrogen if the animal energy is derived from partial decomposition of the food substances. In the case of ascarids this was not found by Bunge to be the case. No hydrogen could be detected, nor did oxygen disappear if supplied to the worms after they had existed for a day without it. Many cases are known in which the animal organism is protected from poisons by their oxidation in the cell, and it is known, too, that there may exist in the cell easily oxidisable substances. The assumption of the theory of active oxygen therefore cannot be said to have got beyond the hypothetical stage (Abderhalden). We must therefore look for a hypothesis which includes the known facts particularly the fact that the cell seems capable of exercising the function of *selective* oxidation.

Such an hypothesis must rest upon the presence in the cell, of ferments which regulate the preparation of food for oxidation, and secondly its oxidation by the oxygen in solution in the cell juices.

¹ Bunge. *Zeit. Physiology. Chem.* 14, 318. 1890.

This was first suggested by Traube¹ who assumed the presence of an oxygen carrier. Schmieberg² has mentioned the possibility of such ferments and Jacquet³ has proved that extracts of organs can act as carriers of oxygen, and that the *principles* causing this can be precipitated by alcohol and destroyed by heating to 100°C.

During the last 15 years a large number of such ferments have been detected in both animal and vegetable tissues, capable of assisting in the oxidation of a number of organic substances of a more or less stable nature. Palladin has examined the pigments produced by the respiration of plants and summarized the processes as follows:—

<i>Primary process.</i>	<i>Secondary process.</i>
Anaerobic enzyme zymase.	Oxygen
Katalase, Reductase.	Respiratory oxidase, phytohaemalin.
Fermentation products alcohols and other bodies.	Respiratory products.
	Carbon dioxide and hydrogen.

Bach⁴ summarizes the recent knowledge on the subject of oxidising enzymes in cell oxidation.

(1) In order to utilize the oxygen of the air to effect oxidation an enzyme (an *oxygenase*), is secreted, which is readily oxidised fixing molecular oxygen to form a peroxide.

(2) A second enzyme (the *peroxydase*) which accelerates the oxidising action of the peroxides by acting on them in a similar way to ferrous sulphate on hydrogen peroxide.

(3) The peroxides are readily transformed by hydrolysis into hydrogen peroxide which is also formed as a primary product during hydrolytic oxidation. Owing to its rapid rate of diffusion the accumulation of hydrogen peroxide might damage cell protoplasm, to guard against this the cell produces an enzyme *catalase* which rapidly decomposes hydrogen peroxide into water and inert oxygen. *Catalase* thus acts as a regulator of the respiratory process.

(4) To effect hydrolytic oxidation an enzyme *perhydridase* is present, which accelerates both oxidation and reduction just as do the metals of the platinum group.

¹ Traube. *Theorie der Ferment Wirkungen*, Berlin, 1858.

² Schmieberg. *Arch. Exper. Path. Pharm.* **14**, 288. 1881.

³ Jacquet. " " " **29**, 386. 1892.

⁴ Bach. *Arch. Sci. Phys. Nat.* **35**, 240—262. 1913.

The *reductase* consists of the enzyme, water, and air oxidisable substances, which fix the oxygen derived from the water, leaving the hydrogen free to effect reduction¹.

Bach and Chandal's theory with regard to the mechanism of cell oxidation and more particularly oxidation in the vegetable cell has been examined and criticised by Moore and Whitley².

These authors as a result of their investigations show a difference between the oxidising action of various vegetable juices and conclude that all such juices show the presence of only one type of enzyme engaged in the process of oxidation, this they term a *peroxidase*. They moreover suggest that this enzyme synchronises with the class of hydrolytic ferments and with the active bodies in natural and immune sera in forming a connecting link between them.

In all three classes of enzymic action three interacting bodies are required. In the case of the hydrolysing enzymes there is (a) the *combining substrate*, the food stuffs, carbohydrate, or fat (b) the *combining body*, the elements of water, finally—intermediary acid or alkali, in the presence of which alone the ferment is active (c) the *catalyst*, one of the digestive or other hydrolytic ferments, example, *pepsin*, *trypsin*, *amylase*, *zymase*, *lipase*.

In the case of *oxidising ferments* we have (a) *substrate*, the oxidisable substances, such as tyrosin, the naturally occurring phenols in the plants, or the chromogenetic indicators used by Moore and Whitley in their experiments; (b) the *combining body*—oxygen yielded either by hydrogen peroxide or by organic peroxides; (c) the *catalyst*, enzymes such as *tyrosinase*, *laccase*, etc.

In the case of immune sera there is (a) the *substrate*, the cell or bacterium to be dissolved or the toxic or foreign substances to be attacked or rendered inert, (b) the *combining body*—the complement or thermo-labile substance in the absence of which the reaction cannot proceed, and (c) the *catalyst*, the specific immune body or anti-body which attacks and disintegrates the foreign cell, or neutralizes the toxic substances.

One of the most interesting and important of these ferments from the point of view of this paper is the so-called *tyrosinase*. This substance was first found by Bertrand³ in many genera of the Fungi in which it is associated with another oxidase *laccase* which however only acts on quinol and pyrogallol.

¹ *Abstract Jour. Chem. Soc. CIV*, 1913, p. 543.

² Moore and Whitley. Properties and Classification of the Oxidising Enzymes. *Bio Chem. Jour.* 1909, p. 136.

³ Bourquelot and Bertrand. *Jour. Pharm. Chem.* 6, 3, 177. 1896.

„ „ „ *Bull. Soc. Mycol. France*, 18, 27. 1896.

„ „ „ *Compt. rend.* 122, 1132, 1215. 1895.

Tyrosinase acts on tyrosin (hydroxyphenyl alanin) in the presence of oxygen or air forming a dark blue black solution (melanine). The dark colour of old and broken fungi is due to this oxidised tyrosin. The same or else a similar enzyme has been identified in the stomach juices of starved meal worms by Biedermann¹ which will act upon tyrosin. The darkening in colour of some insects after death, the so-called melanosis, has been shown by Von Furth and Schneider² to be the result of the action of a similar oxidase ferment. The larva of *Attagenus undulatus*, one of the insects infecting wheat in the Punjab, shows marked evidence of melanosis after death:—while living the larvæ are pale yellow or almost white in colour with a tendency to red. After death this changes to a dark brown. The presence in both vegetable and animal tissues of oxidase ferments capable of bringing about the oxidation of such inert substances as tyrosin which are able to resist all but the most powerful of the reagents at the disposal of the chemist, indicates that they play an important part in the process of cell oxidation—the final stage of respiration, but further evidence seems wanting to show that respiration is actually due to the presence of these ferments, that it is in fact an enzymic process.

To prove this successfully we must produce the ordinary effects of respiration under conditions in which the animal as a living organism has been destroyed, but in which any ferments present in the tissues have been left unimpaired, and secondly, we must show that the destruction of the enzyme results in the checking of all such respiratory processes. This result has been achieved in the following series of experiments.

Experiment.

The enzyme. Larvæ of *Attagenus undulatus* were collected in quantity by placing folded sheets of brown paper in masses of infected grain, the larvæ either to avoid the light or for the sake of warmth, collected in the folds on the underside of the paper. 192 grams of the larvæ, separated and collected in the afternoon were allowed to stand overnight in a beaker. On the following morning it was noticed that a considerable quantity of moisture was deposited on the upper portion and on the cover of the beaker. It was also noticed that these larvæ in mass had a temperature of 22.1°C. On exposure to fresh air and transference to a second beaker the temperature of the larvæ rose from 22.1°C to 28.9°C in the course of 15 minutes, indicating a

¹ Biedermann. *Pflüger's Arch.* **72**, 105. 1898.

² Von Furth and Schneider. *Hofmeister's Beiträge* **1**, 229. 1901.

rapid reaction with the fresh oxygen with which they had been brought in contact in their transfer from the beaker in which they had been stored overnight.

The above quantity of larvæ was mixed with an equal weight of fine sand and reduced to a pulp, chloroform water being added from time to time during the process of grinding. In all 22 c.c. of water were added. The mixture was allowed to stand for one hour at room temperature, and then strained through a fine cloth. The filtrate measured 170 c.c. and was of a grey colour and was fairly thick. 250 c.c. of 95% alcohol were then added and the precipitate formed, separated by filtration through a Büchner funnel. The precipitate was taken up with chloroform water, filtered, and again precipitated with 95% alcohol. The second precipitate was washed with a small quantity of water to remove the alcohol and then suspended in 100 c.c. of water and covered with a layer of toluene and placed in a stoppered bottle.

A second solution was prepared using only chloroform water to extract the powdered larvæ. No precipitation with alcohol was here resorted to. These two solutions were used to test for *tyrosinase*. Pure tyrosin prepared by Fischer's method from silk by acid hydrolysis was recrystallized from water, and aqueous solutions of 0.05%, 0.1% and 0.5% strength prepared. The action of the enzyme was tested by adding to 5 c.c. of the above solution contained in a test-tube 5 c.c. of the enzyme solution, closing the tube with a cork and maintaining it at a constant temperature of 30°C. After periods varying from 1 to 18 hours a dark bluish black colour is developed in the upper layer of liquid (nearest the air). This colour was more intense in the case of the 0.1% solution of tyrosin and with the unprecipitated enzyme solution.

The action of the enzyme was then studied on (1) eugenol (2) carvacrol (3) toluidine (4) o, m & p. xylene (5) phenol-phthalin (6) thymol. .

2% solutions of these substances were prepared in alcohol of 20% strength (except phenol-phthalin which was of 0.25% strength in 50% alcohol). 5 c.c. of the test and 5 c.c. of the enzyme solution were as before placed in a corked tube, shaken, and placed in a constant temperature bath at 30°C. for 18 hours. All these substances showed signs of oxidation, but it was more developed in the case of the three xylenes.

In the case of the enzyme solution prepared without alcoholic precipitation, a slight black colour itself developed which grew more marked after the lapse of some time. This indicates the presence of tyrosin as well as tyrosinase in the body of the weevil, both of which substances pass into solution

in chloroform water, the amount of tyrosin is evidently very small. In order to test the hypothesis that ozone or nascent oxygen is or may be present in the cell during active oxidation, a solution of tyrosin mixed with enzyme solution was subjected to the action of ozone. If the hypothesis were correct we should expect more rapid oxidation of the tyrosin by this means. As a matter of fact no colour was developed, the enzyme being evidently destroyed by even traces of ozone. The action of the enzyme was completely inhibited by boiling the solution.

Ether also appears to destroy the enzyme. An attempt was made to prepare a solution of the enzyme after removal of the fat by ether. The crushed larvæ mixed with sand were first extracted with ether to remove fat and afterwards with chloroform water. The aqueous extract so prepared failed to bring about the oxidation of tyrosine. Either the enzyme had been destroyed or was entirely removed in the ethereal washing.

Influence of acid or alkali on the activity of the enzyme.

The aqueous extract of the crushed larvæ was found to be faintly acid to litmus, this we should expect as partial oxidation of the fats would take place in the process of preparing the solution, with the formation of acid bodies. The solution so prepared was found to give but a slight reaction towards tyrosin while in this acid condition. Rendering the liquid faintly alkaline with either ammonia or sodium carbonate induced a much more rapid reaction, ammonia being more effective than sodium carbonate.

Consequently in all subsequent tests made for comparison the enzymic solutions were rendered faintly alkaline with ammonia. Abderhalden and Guggenheim¹ showed the necessity of using alkaline solution in working with tyrosinase. These authors used sodium carbonate of 0.04% strength, tyrosin of 0.05% strength in working on *tyrosinase*.

In the higher animals there is no doubt that alkaline phosphates are always present in the plasma and these alkalies play an important part in regulating the amount of carbon dioxide held in solution. The protein substances are actually present in some cases as alkaline salts in the serum, and as the CO₂ concentration increases it undoubtedly replaces the protein in

¹ Abderhalden and Guggenheim. *Zeit. für Physiolog. Chem.* 54, 331.

its combination with the alkali¹. The oxidase enzymes then are probably adjusted to work under alkaline rather than under acid conditions and this observation of ours confirms that of Abderhalden and Guggenheim.

EXPERIMENT.

Effect of starving the larvæ with a limited supply of air.

Fifty grammes of larvæ were placed in the incubating tube of the apparatus described on page 231 and the gases of the tube analysed at the end of twenty-four hours, and again after three or four days. The following table shows the effect of the treatment.

TABLE XXXII.

No. of experiment	Date of charging the tube	Date of analysis	Carbon dioxide %	Oxygen %
Experiment 1	18-3-1914	19-3-1914	24.8	1.08
		23-3-1914	26.4	0.60
Experiment 2	27-3-1914	28-3-1914	25.0	1.10
		31-3-1914	26.6	1.09

We expected to find that as the oxygen of the air present in the incubation tube became exhausted the larvæ would die from asphyxiation, the actual lethal period varying according to the "condition" of the larvæ. But it is clear from the above figures that the process of respiration has continued after the exhaustion of the supply of atmospheric oxygen.

Taking the composition of the air by volume to be 21% oxygen and, 79% nitrogen and other gases, we see that the amount of carbon dioxide produced in excess of the atmospheric oxygen used is from 4.8% to 6.6%. For we see from the above figures that the last 1% of atmospheric oxygen present in the tube has not been available for respiration—in other words, the animal has not been able to make use of this—but that after the removal of 20 out of the 21

¹ Serloti. Hoppe-Seyler. *Medizin. Chem. untersuch. Berlin*, 1868.
 „ *Pflüger's. Arch.* **58**, 511. 1894.
 „ *die Kohlensäure des Blutes*, p. 11, Bonn, 1864.
 „ *Memoir de l' Acad. de St. Petersburg*, **26**, 60. 1879.

volumes of oxygen present (that is 95% of the oxygen originally present) the larvæ fall back on an internal oxygen supply, and respiration continues with the production of a further 5% or 6% of carbon dioxide. Since there is no supply of stored oxygen in these larvæ similar to that in the blood of the higher animals we must concede that the carbon dioxide has resulted from the partial decomposition of chemical substances rich in oxygen, present in the tissue of the larvæ. Most insects in the larval stage secrete large quantities of fat which serve them as a reserve food-supply during the pupal stage. We therefore analysed the larvæ of *Attagenus undulatus* both before and after starving in an enclosed space similar to the above experiment. In this method 50 grams of larvæ were taken for analysis, crushed with excess of sand, and extracted with ether in a Soxhlet's apparatus, and the amount of fat in the ethereal extract determined.

TABLE XXXIII.

Effects of starvation in an enclosed atmosphere on the fat contents of the larvæ of Attagenus undulatus:—

Percentage of fat in the fresh larvæ	28.73%
Percentage of fat present in the same larvæ starved for 5 days	26.3%

The time at our disposal did not allow us to investigate the exact chemical nature of the fats, nor is this essential to the enquiry. These will probably consist for the most part of glycerides of the saturated fatty acids, and both the trihydric alcohol glycerine $\text{C}_3\text{H}_8\text{O}_3$ and the fatty acids combined with it ($\text{C}_n\text{H}_{2n+1}\text{COOH}$) can under suitable conditions be made to yield a supply of energy by partial reduction, with the formation of carbon-dioxide and carbon compounds richer in carbon and hydrogen, or even of hydrogen itself, as is the case in the anaerobic fermentation of cellulose.

In all probability hydrolysis of the fat first takes place with the formation of fatty acids and glycerine, and this glycerine is almost certainly the source of the energy indicated by the presence of the excess of carbon dioxide produced, as in the reduction of the higher fatty acids a small amount of carbon-dioxide would be accompanied by the production of relatively large quantities of hydrocarbons which could not have escaped notice. In the experiments

stated above large quantities of hydrocarbons or of hydrogen were not produced though traces were found.

The next step was to obtain proof that the reactions noted above were enzymic. In order to do this it was merely necessary to destroy the larva as a living organism but under such conditions as would leave the enzymic contents of the tissue unimpaired. If respiration is then a result of enzymic action, either simple or complex, we should obtain an absorption of atmospheric oxygen, and after this had all disappeared, a further production of carbon-dioxide from the breaking down of the hydrolysed fats present.

Experiment. Varying quantities of fresh larvæ were reduced to a fine powder with excess of sand (recently ignited and cooled to destroy any organic matter, bacteria, etc.), the amount of sand added being regulated so as to yield a fairly dry granular mass after grinding.

A little chloroform (and in another experiment toluene) was added to the mass in grinding to render this sterile. The incubation tube described above was then sterilized with chloroform vapour (or toluene) and the sand-larval mass introduced. Chloroform vapour was now passed through the whole apparatus for 20 minutes to render the incubation tube and its contents sterile, and this vapour was afterwards removed by a current of sterile air passed for from 20 to 30 minutes. The tube was then closed and kept at a constant temperature of 30°C and the gases of the tube analysed from time to time. The precautions taken to ensure the sterility of the tube and its contents were to prevent any bacterial changes taking place in the crushed material. A control experiment was done subjecting the mass to steam heat in an autoclave for 20 minutes at 115°C and as this failed to destroy the enzyme a second control was done destroying the enzyme by subjecting it to a temperature of 125° C. for 30 minutes in the autoclave.

In connection with the difficulty here experienced of destroying the "oxidase" by steam heat we would cite Wood's¹ experience in the case of tobacco oxidase; he found this enzyme to be very refractive to destruction by heat. Moore and Whitley² also refer to the difficulty of destroying vegetable "peroxidases" by boiling their solutions and cite that potato juice may be boiled for half a minute without accomplishing this destruction.

¹ Wood. *Bull. U. S. Dept. of Agriculture* No. 18, p. 17.

² Moore and Whitley. *Bio-Chem. J.* Vol. IV, 1909, p. 139.

The following table gives the results obtained :—

TABLE XXXIV.

Analysis of gases expired by sterile crushed larvæ of A. undulatus with a limited supply of air at a temperature of 30°C.

Experiment	Time of incubation in hours	Carbon-dioxide %	Hydrogen %	Methane %
(A) 7.86 grams of larvæ sterilized with toluene	18 hours	11.3	0.14	...
	30 "	21.18	2.3	2.4
	45 "	21.7	1.7	2.0
(B) 9.47 grams of larvæ sterilized with chloroform.	18 hours.	22.7	2.05	0.98
	30 "	24.69	0.65	1.7
	45 "	24.8	0.85	0.97
(C) 17.05 grams of larvæ sterilized with chloroform.	18 hours.	20.8	1.03	1.54
	30 "	29.2	1.17	1.94
	45 "	34.02	1.92	2.26
(D) 5.68 grams of larvæ sterilized with chloroform.	18 hours.	12.8	0.74	1.8
	30 "	not analysed.	not analysed	...
	45 "	22.1	1.02	1.9
(E) Control 16.2 grams of larvæ sterilized in steam autoclave for 20 minutes at 115°C.	18 hours.	0.66	0.8	0.6
	30 "	1.9	0.9	1.1
	45 "	8.0	1.0	1.06
(F) Control 6.4 grams of larvæ sterilized in the steam autoclave for 30 minutes at 125°C	18 hours.	0.07	0.6	0.8
	30 "	not analysed.	..	not analysed.
	45 "	0.2	0.58	1.9

It is very clear from these figures that the chemical processes of respiration as indicated by the absorption of oxygen and the production of carbon-dioxide have gone on in the larvæ after death in an exactly similar manner to those in process during life. It is in fact respiration after death and the proof that the action is enzymic is shown in the analyses of the gases in experiments E and F where the enzyme has been partially or entirely destroyed by steam heat. The importance of this result cannot be too greatly emphasised both in its theoretical and practical aspect. It disposes of all the older theories regarding the mechanism of the respiratory process and proves beyond doubt that this is enzymic. It meets the demand of the physiologist that respiration is really a cell function no matter how or by what means the oxygen

actually reaches the cell plasma or whether the cell is vegetable or animal and that the actual oxidation of the nutrient present there, is under the control of the cell protoplasm. The presence of oxidases in plant tissue indicates that respiration in the vegetable cell is the same in all its essential features as that in the animal cell, but the greater demands of the latter for energy result in a larger display of the chemical processes attendant on respiration. It is in such members of the vegetable kingdom as exhibit abnormally rapid growth like the fungi, that we find these oxidases in greatest abundance, and their presence there evidently indicates that respiration is proceeding at a rapid rate. The change in colour of these bodies after death is similar to the phenomenon of melanosis in the insects, and there, as in the case we have examined, we shall no doubt find that respiration proceeds after the death of the plant, using the term death to cover the disintegration of the plant as a whole but not the destruction of the enzymes.

It is well known that aerobes placed in an atmosphere of hydrogen continue to produce carbon-dioxide until death ensues, and that even when placed in a vitiated atmosphere containing only 3% or 4% of oxygen a volume of carbon-dioxide is evolved which greatly exceeds the amount of oxygen consumed. Stich has shown that in such cases the plant accommodates itself to the changed circumstances and after some time the diminished oxygen supply suffices for the diminished respiratory activity.

What is of equal importance it has been observed by many workers that in the so-called intramolecular respiration of plants reduction products of the sugars such as alcohol and hydrogen in addition to carbon-dioxide have been found.

Pfeffer states that the intramolecular respiration of plants is not directly connected with the decomposition of protein substances but he overlooks the fact that it may have a very important bearing on the vitality of the embryo in throwing the whole burden of supplying the necessary energy to maintain the vital processes on the internal cleavage of sugar and protein substances as well as intermediary compounds of these.

The resistance of aerobes to a vitiated atmosphere or to use Pfeffer's words "the intensity and character of intramolecular respiration" is dependent upon the specific nature of the plant and upon the quality and quantity of the available food materials.

Reference may be made to Pfeffer's *Physiology of Plants*, volume 1, page 536, *et seq.*, where a bibliography of the original papers dealing with the respiration of plants is given.

The next important step in proving the function of these oxidases in animal tissues is to examine their action on the purin bases and particularly their action on xanthin. This has already been done by Von Burian and by Wiechnowski and H. Wiener.¹ These authors obtained an enzyme capable of oxidising xanthin to uric acid by extracting the finely powdered organs with a 0.05% solution of sodium carbonate. We hope to repeat this work on *A. undulatus* when the larvæ are again available in quantity.

We may now venture to interpret our previous results and observations in the light of these latter discoveries.

Taking first the case of carbon-dioxide and its effect on the larvæ of *A. undulatus* we have already noted that on first introducing the larvæ into the gas a short period of intense activity extending over only a few seconds, was followed by a lengthy period of coma varying from 63 hours in one experiment at 30°C to 87 hours in another at the same temperature. When first introduced into the gas, the tracheal system of the insect is not uniformly charged with air. In the case of man it has been shown that it is only the composition of the air in the alveoli which regulates the rate of gaseous exchange between the outer air and the blood gases^{2 3} and so in the insect it will be this composition of the air in the finer capillaries of the tracheal system which will come into play. Evidently then the first effect of a decreased carbon-dioxide exchange from the insect to the outer air due to the rapidly increasing concentration of carbon-dioxide in the tracheal system, will be instantly followed by muscular effort both of the respiratory muscles of the trachea in their increasing demand for air, and of the whole insect to escape from an undesirable environment. In a very short time, however, the insect is cut off from gaseous oxidation and all muscular activity ceases. It now enters on a more or less lengthy resting period from which, if not restored to air at a suitable temperature, it will ultimately and imperceptibly pass the boundary between life and death. Since it is clear that during this period the organism is quite cut off from all external supplies of oxygen in the gaseous form, and since any oxygen present in the insect will be rapidly used up or passed by diffusion into the outer atmosphere of carbon-dioxide in the trachea, and as we have shown above the insect is incapable of using more than 95 per cent. of the atmospheric oxygen when the air is replaced by carbon-dioxide, it must be making use of chemically combined oxygen to maintain the life processes during the period of coma which precedes death.

¹ Von Burian, Wiechnowski and Wiener, *Hof. Beiträge* 9, 247 and 295. 1903.

² Wolffberg. *Pflüger's Arch.* 4, 465, 1871, and 6, 23, 1872.

³ Nussabaum. *Pflüger's Arch.* 7, 296. 1873.



This energy as we have already seen is derived from the reserve food in the form of fats, and is rendered available by an oxidase enzyme. The wide difference between the lethal periods for carbon-dioxide at different periods of the year shown in graphic form in Figure 4 as well as the difficulty experienced in obtaining concordant result in the same experiment with all the insects (see Table XXVII, page 234) indicate that the personal factor in each insect is regulated by the activity of its enzymic contents at the time of the experiment. Since these enzymes then play the part they seem to do from these observations described above, their presence is clearly connected not only with the process of respiration but in some modified form controls the supply of energy from the internal combustion of fats which must take place when the animal is cut off from air, either artificially as in the above described experiment where we have placed it in an atmosphere of carbon-dioxide or other gas, or in the natural state during the pupa and metamorphosis stage in which there appears to be no provision for ordinary respiratory processes. A parallel case to this may be cited in that of the higher animals which hibernate. Such animals are well-known to conserve a considerable amount of reserve food in the form of fat; issuing from their winter quarters they are invariably lean and most or all of the fat has disappeared.¹ In these cases we know that respiration continues at a slower rate, but it may be helped by internal respiration. We (the authors) have no information regarding this process and in the light of our results it appears to offer a fertile field for enquiry on similar lines. It will be remembered that we have shown carbon-dioxide to have an injurious effect on the germinating power of wheat, and we have not had time to examine the comparative effect of hydrogen and nitrogen on this value in addition to that of carbon-dioxide but respiration in the embryo of the grain is no doubt carried on in exactly the same manner by means of enzymes, hence the deleterious effect of carbon-dioxide in cutting off the supply of atmospheric oxygen and so allowing the embryo a less supply of energy from the nutrient foods contained in it, viz., only the energy available from the cleavage of the food substances.

We are at present unable to offer a complete explanation of the shorter lethal period in the case of the gases of less density. The laws of gaseous diffusion must apply, and be in part responsible for the shortening of the period in the case of gases lighter than carbon-dioxide, for in the production of carbon-dioxide by the cleavage of compounds rich in oxygen such as evidently takes place in the larvæ of *Attagenus undulatus*, the rate at which this will

¹ Carlier, E. W., and Evans, C. A. L. *Journal of Anatomy and Physiology*. Vol. XXXVIII, pp. 16—31.

diffuse out *viâ* the tracheæ into the outer atmosphere, must be greater, as this atmosphere is made one of less density, and thus far our results confirm Graham's supposition. But this is not all, for we have seen that no numerical relationship can be established between the rates of diffusion of the different gases and the length of the lethal period.

The shortening of the lethal period with increase of temperature, proceeding as it does in a regular manner in some of the cases examined, indicates this period is in all probability a function of a chemical reaction and obeys the laws governing chemical reactions. This is no doubt true since both hydrolysis and cleavage as the result of enzymic activity will proceed at an increasing rate with the rise in temperature until the optimum temperature for the working of the enzyme is reached, after which the curve will break away to the ordinate. This point evidently has not been reached in our experiments with carbon-dioxide, hydrogen, or nitrogen. More rapid hydrolysis and cleavage will result in a more rapid production of carbon-dioxide, a more rapid consumption of the available food, and a general tendency to shorten the coma stage or lethal period. Thus far we seem justified in interpreting the results obtained with the effect of the gases carbon-dioxide, hydrogen and nitrogen on the beetles *A. undulatus*, *R. dominica*, and *C. oryzae*.

SUMMARY.

This portion of the enquiry has proved the process of respiration to be the result of enzymic activity under the control of the cell and experimental evidence in support of this is produced in separating the particular type of oxidation which takes place in the larvæ of *Attagenus undulatus* from the living processes.

The inert gases carbon-dioxide, hydrogen, and nitrogen, have been shown to have very different lethal periods, and the lighter or less dense the gas, the shorter the time taken to kill the insect.

Increase in temperature also brings about a shortening of the lethal period. Respiration being shown to be an enzymic action the ordinary chemical laws governing the rate of chemical reaction will apply, increasing velocity of reaction with increasing temperature.

Gaseous diffusion also plays some part here in the less dense atmosphere hastening the diffusion of the carbon-dioxide produced by internal respiration, and so accelerating the consumption of the available food. The lethal

periods do not coincide with the diffusion ratios calculated from the gas densities.

We are forced to the conclusion that no inert gas (such as carbon-dioxide) can be economically used as an asphyxiating agent for these insects, owing to their ability to enter on a "hibernating" stage when atmospheric oxygen fails them and also because carbon-dioxide itself materially affects the germinating power of wheat. We must therefore turn to the use of chemical deterrents or mechanical methods of treatment.

CHAPTER V.

THE EFFECT OF MOISTNESS AND DRYNESS.

This subject has been dealt with by several writers, and a summary of the information on the subject is given by Noël Paton,¹ who quotes the conclusions arrived at by Fletcher. The most important is number three which states:—"Whilst containing less than 8 per cent. (moisture) stored wheat is immune from attack by weevil, and any weevils which may obtain access to it are soon killed off."

From this Noël Paton was led to conclude that desiccation would be an effective means for preserving stored grain, and goes so far as to say:—"But in view of the facts demonstrated by Messrs. Fletcher and Leather the probability is that the elevators will have the effect desired, not through employing gas of any kind but through the operation of their drying appliances."

This conclusion is, however, premature, for the experiments carried out by Fletcher were with *C. oryzae* only, but by the use of the term "weevil" in the conclusion drawn from the experiments, a wider significance is conveyed to the lay mind than the experiments warranted, since all insects attacking wheat are "weevils" to the uninitiated.

As has been previously pointed out, the insects which have to be dealt with in the Punjab are three in number, one being *C. oryzae* and it was necessary to know whether the other two *A. undulatus* and *R. dominica* behaved in the same way towards dryness as *C. oryzae* had been shown to do.

Two series of experiments have been carried out, each of a different nature.

Whilst at Pusa one of us (A. J. G.) carried out a series of tests in collaboration with Leather on similar lines to those conducted by Lefroy and Fletcher, but dealing with each of the insects concerned separately. The experiment was divided into two sets, in the one, glass stoppered bottles were used and in the other corked tubes sealed with paraffin wax. The vessels were divided into series and were filled with wheat containing roughly the following percentages of moisture, 5%, 7%, 10% and 15%, and into each

¹ *Loc. cit.*

vessel 20 live insects were placed. In the case of *C. oryzae* and *R. dominica* adult beetles were used, but with *A. undulatus* larvæ only, as adults were not obtainable (it was not known at the time that these experiments were conducted that it was only in the larval stage that this insect damaged the wheat). The wheat which was placed in the stoppered bottles was fumigated with carbon-bisulphide before being moistened or dried so as to bring its moisture content to the required amount, but that which was used in the tubes was not fumigated but had been carefully examined and selected. The reason for this was, that in some preliminary experiments with fumigated wheat, the insects had all died, and it was thought that perhaps the fumigant may have been responsible for this. For each percentage of moisture there were three bottles and three tubes for each species, so that the experiment was done in triplicate in each set.

The series in the glass bottles were started on 22nd October 1913 and those in the tubes on 24th November. Both remained undisturbed in the laboratory until 1st December when, the temperature falling below what was considered desirable, they were placed in a large constant temperature chamber at 30°C., where they remained until January 1914. All the vessels were opened and examined between 16th and 23rd January, and the results obtained are given in the following tables in which the numbers 1, 2 and 3 refer to the stoppered bottles containing fumigated wheat, and 4, 5 and 6 refer to the paraffined corked tubes containing unfumigated wheat in each case.

TABLE XXXV.

A. undulatus.

No.	Percentage of moisture	No. of insects put in	No. of insects found	No. of insects alive	No. of insects dead	REMARKS
1	5%	20	19	...	19	3 cast skins.
2	5	20	19	10 (¹)	9(²)	(¹) 8 larvæ, 2 beetles. (²) 3 larvæ, 6 beetles. 45 cast skins.
3	5	20	16	...	16	3 cast skins.
4	5	20	20	...	20	
5	5	20	23	17(³)	6(⁴)	(³) 15 larvæ, 1 pupa, 1 beetle. (⁴) 2 larvæ, 4 beetles, 36 cast skins. Of the live larvæ 4 were very small and had evidently hatched from eggs.
6	5	20	18	16(⁵)	2(⁶)	(⁵) 16 larvæ. (⁶) 1 larva, 1 beetle, 42 cast skins.

TABLE XXXV—*conld.**A. undulatus*—*concl.*

No.	Percentage of moisture	No. of insects put in	No. of insects found	No. of insects alive	No. of insects dead	REMARKS
	%					
1	7	20	18	...	18	5 cast skins.
2	7	20	19	14 ⁽⁷⁾	5 ⁽⁸⁾	⁽⁷⁾ 8 larvæ, 1 pupa, 5 beetles. ⁽⁸⁾ 5 beetles, 63 cast skins. Eggs found.
3	7	20	19	...	19	38 cast skins.
4	7	20	17	16 ⁽⁹⁾	1 ⁽¹⁰⁾	⁽⁹⁾ 15 larvæ, 1 beetle. ⁽¹⁰⁾ 1 beetle, 39 cast skins.
5	7	20	20	...	20	4 cast skins.
6	7	20	19	...	19	
1	10	20	16	...	16	2 cast skins.
2	10	20	17	..	17	13 cast skins.
3	10	24	19	...	19	6 cast skins.
4	11	20	15	13 ⁽¹¹⁾	2 ⁽¹²⁾	⁽¹¹⁾ 9 larvæ, 4 beetles. ⁽¹²⁾ 2 larvæ, 2 beetles. 38 cast skins.
5	11	20	17	...	17	
6	11	20	14	3 ⁽¹³⁾	11 ⁽¹⁴⁾	⁽¹³⁾ 3 larvæ. ⁽¹⁴⁾ 11 larvæ, 19 cast skins.
1	12	20	17	...	17	9 cast skins.
2	12	20	11	5 ⁽¹⁵⁾	6 ⁽¹⁶⁾	⁽¹⁵⁾ 5 larvæ. ⁽¹⁶⁾ 6 larvæ. 32 cast skins.
3	12	20	19	...	19	5 cast skins.
4	12	20	16	15 ⁽¹⁷⁾	1 ⁽¹⁸⁾	⁽¹⁷⁾ 14 larvæ, 1 pupa. ⁽¹⁸⁾ 1 larva, 30 cast skins. An infection of <i>C. oryza</i> had occurred.
5	12	20	20	...	20	
6	12	20	18	...	18	
1	15	20	20	...	20	
2	15	20	17	...	17	
3	15	20	19	...	19	3 cast skins.
4	15	20	18	...	18	
5	15	20	20	...	20	
6	15	20	17	12 ⁽¹⁹⁾	5 ⁽²⁰⁾	⁽¹⁹⁾ 12 larvæ. ⁽²⁰⁾ 5 larvæ, 30 cast skins. An infection of <i>C. oryza</i> had occurred.

TABLE XXXV—*contd.**R. dominica.*

No.	Percentage of moisture	No. of insects put in	No. of insects found	No. of insects alive	No. of insects dead	REMARKS
1	$\frac{5}{5}$	20	17	3	14	Several eggs found.
2	5	20	20	...	20	
3	5	20	20	...	20	
4	5	20	20	...	20	
5	5	20	19	...	19	
6	5	20	18	16	2	
1	7	20	18	16	3	
2	7	20	20	...	20	
3	7	20	20	...	20	
4	7	20	21	14	7	
5	7	20	19	...	19	
6	7	20	20	15	5	
1	10	20	28	12	16	
2	10	20	20	...	20	
3	10	20	20	...	20	
4	11	20	20	...	20	
5	11	20	20	...	20	
6	11	20	20	14	6	
1	12	20	26	23	3	
2	12	20	20	...	20	
3	12	20	19	...	19	
4	12	20	20	...	20	
5	12	20	19	...	19	
6	12	20	18	...	18	
1	15	20	20	9	11	
2	15	20	20	...	20	
3	15	20	21	...	21	
4	15	20	20	...	20	
5	15	20	20	...	20	
6	15	20	17	...	17	

TABLE XXXV—concl'd.

C. oryzae.

No.	Percentage of moisture	No. of insects put in	No. of insects found	No. of insects alive	No. of insects dead	REMARKS
	%					
1	5	20	21	..	21	
2	5	20	20	...	20	
3	5	20	22	...	22	
4	5	20	20	...	20	
5	5	20	20	...	20	
6	5	20	20	...	20	
1	7	20	21	...	21	
2	7	20	22	...	22	
3	7	20	21	...	21	
4	7	20	19	...	19	
5	7	20	19	..	19	
6	7	20	24	...	24	
1	10	20	20	...	20	
2	10	20	21	...	21	
3	10	20	44	17	27	
4	11	20	25	...	25	
5	11	20	25	...	25	
6	11	20	23	..	23	
1	12	20	20	...	20	
2	12	20	25	...	25	
3	12	20	44	12	32	
4	12	20	20	...	20	
5	12	20	22	...	22	
6	12	20	20	...	20	
1	15	20	23	...	23	
2	15	20	20	...	20	
3	15	20	27	...	27	
4	15	20	20	...	20	
5	15	20	20	...	20	
6	15	20	20	...	20	

An examination of these results shows that although wheat containing less than 8 per cent. moisture is immune from the attacks of *C. oryzae* (which is the form in which Fletcher should have stated his conclusion), yet with *A. undulatus* and *R. dominica* a very different state of affairs exists. In the case of *A. undulatus* the very reverse is the case, in that, although some of the insects had survived in each of the various percentages of moisture, yet breeding had taken place more frequently in the lower percentages, oviposition apparently having occurred in the cases of 5 per cent. and 7 per cent. moisture. With *R. dominica* some insects had survived under each of the conditions, but it is noticeable that breeding had gone on even with only 5 per cent. moisture. The experiment is open to criticism from the point of view that our knowledge of the condition of the atmosphere inside the bottles is very limited, and the results may have been disturbed by the introduction of other factors, especially in the high percentages of moisture, produced by partial germination or fermentation in the wheat. It was therefore deemed advisable to test the matter in another way.

The second series of experiments was carried out at Lyallpur on quite

different lines. The object of the experiment was to determine the length of time which the insects would live without food and at different temperatures in, on the one hand, an atmosphere saturated with moisture, and on the other hand an atmosphere entirely free from moisture. The results obtained could then be plotted in the form of a curve and the space between the "dryness curve" and the "moistness curve" should be a measure of the sensitiveness of each of the species to moistness or dryness. The insects were confined in test tubes of the shape shown at A in Fig. 7 their activities being restricted to the closed end of the tube by means of the wire gauze plug. In the body of the tube a smaller tube was placed

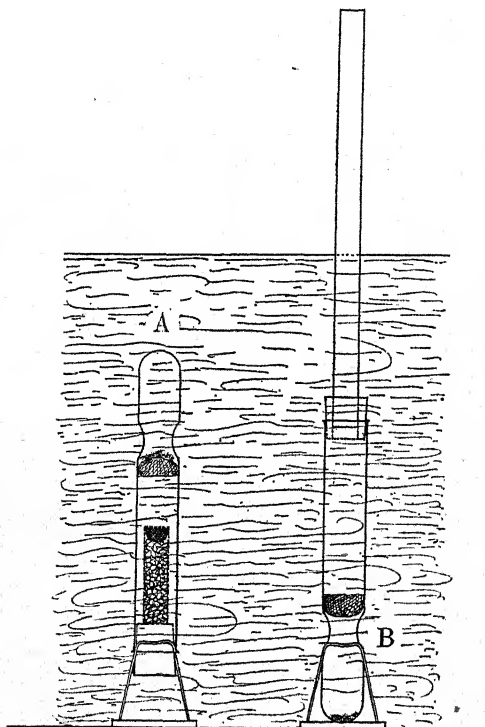


Fig. 7.

which contained the reagent used to produce the atmosphere required, and the whole was sealed by a rubber bung. Each tube, rounded end upwards, was

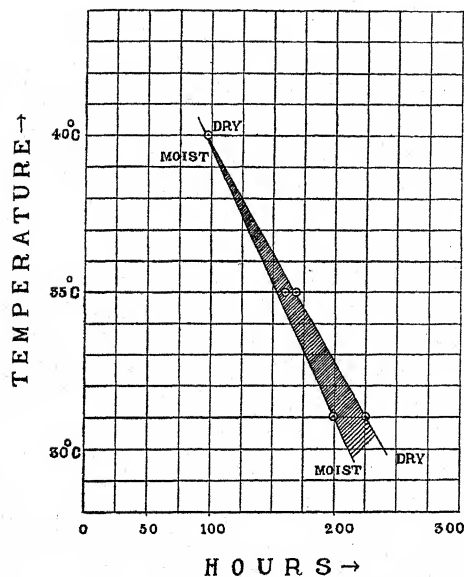
R. dominica.

Fig. 8.

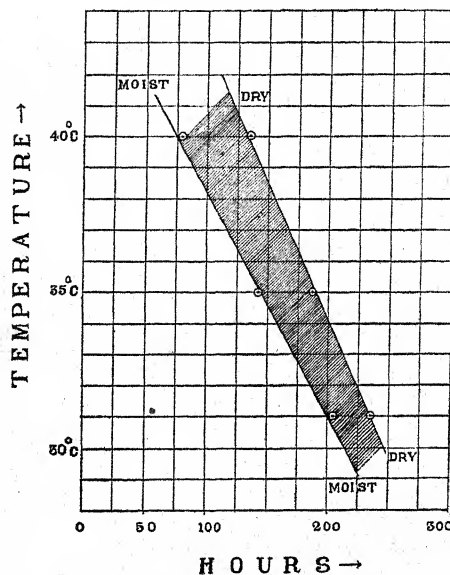
A. undulatus.

Fig. 9.

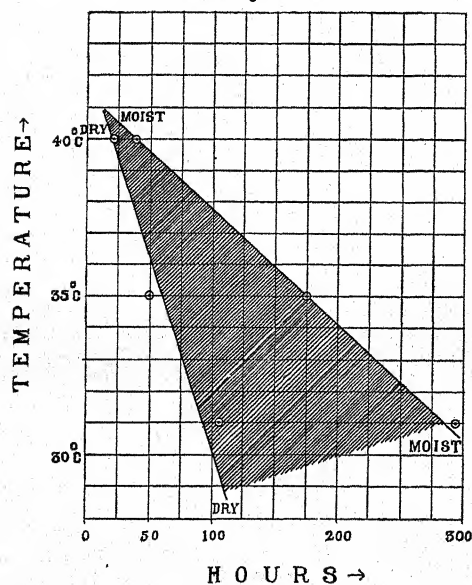
C. oryzæ.

Fig. 10.

then submerged by means of the leaden sinker in a tank of water kept at a constant temperature. In order to produce an atmosphere saturated with moisture, the reagent tube contained small pieces of pumice soaked with a dilute solution of caustic potash, the use of the potash being to absorb any carbon-dioxide which might be given off by the insects; and the dry atmosphere was produced by the use of fused calcium-chloride, which however was also mixed with soda lime to absorb any carbon-dioxide. The control tube used with each of the experiments is shown at B, Fig. 7, the wide

tube piercing the bung being open to the atmosphere above the water in the tank. In carrying out the experiment four moist tubes and four dry tubes were used for each species and each tube charged with ten insects. The control tube was charged with twenty insects. The experiment was carried out at temperatures of 31°C, 35°C and 40°C. The chief difficulty met with was to determine exactly when the insects were dead, for it was found that often when to all appearances death had occurred, the insects on removal from the tube would recover. In practice therefore tubes in which the insects had all apparently succumbed were left for varying periods before they were removed, and in this way a number of periods was obtained some of which were too short and some too long. An average of these figures will give approximately the period fatal under the particular conditions, and the periods given in Table XXXVI are such averages. These were plotted in the curves shown in Figs. 8, 9 and 10 the lethal periods being plotted as ordinates and the temperatures as abscissæ.

TABLE XXXVI.

TEMPERATURE	LETHAL PERIOD IN HOURS					
	<i>A. undulatus</i>		<i>R. dominica</i>		<i>C. oryzae</i>	
	Moist	Dry	Moist	Dry	Moist	Dry
31°C ...	205	235	199	223	295	80
35°C ...	143	188	162	167	173	50
40°C ...	78	134	97	98	38	22

An examination of the curves shows that in the case of *C. oryzae* the dryness curve is steeper than, and is on the left hand side of the moistness curve, and the space between the two curves is considerable. With *R. dominica* the dryness curve is on the right of the moistness curve, but the space between them is very small, and for *A. undulatus* the dryness curve is on the right hand side of the moistness curve and the space between them is more than that of *R. dominica* but less than *C. oryzae*.

The deduction which can be drawn from this is that, whereas dryness has a marked inhibitory effect upon *C. oryzae*, it has practically the same effect as moistness on *R. dominica* and no effect on *A. undulatus*, this insect in fact preferring dry conditions to moist ones. This supports the results obtained in the first experiment.

It is clear therefore from these experiments that desiccation is not a remedy which is effective against all the insects which attack stored wheat in the Punjab, though it is so in the case of *C. oryzae*. *R. dominica* seems to be practically indifferent to either moistness or dryness and *A. undulatus* seems to prefer dry conditions and moisture in excess appears to inhibit its activities.

The results are supported by other investigations. If reference be made to the Tables VII, XII and XV, which give the length of life-history of these insects at different periods of the year, it will be seen that the shortest periods for *A. undulatus* are during May, June and the first half of July which are the hottest and driest months of the year. In the case of *R. dominica* the effect of the moist conditions is not so noticeable, the length of life-history being more influenced by temperature. The case of *C. oryzae* is remarkable, for breeding ceased entirely during the hot dry months of May, June and July and it was not until the moisture conditions had been made sufficiently favourable by the advent of the rains, that development took place.

The distribution of these insects in the Punjab gives further support to these results for if Table I, pages 169 and 170, are consulted, it will be seen that in the drier places such as Sirsa and Lyallpur, where the rainfall is small, *A. undulatus* is the commonest insect found, while in Amritsar, Gurdaspur and places in that district which are closer to the foot hills and have consequently a much higher rainfall, *C. oryzae* predominates.

CHAPTER VI.

REMEDIAL MEASURES AND EXPERIMENTS CONNECTED WITH THEM.

1. *Chemical Deterrents.*

The use of Chemical Deterrents. An account has been published by one of us (A. J. Grove)¹ on the use of naphthalene in preventing insect attacks on stored maize. It was shown that the results obtained by its use were as good as those obtained by fumigation with carbon bi-sulphide and that the germination of the grain was not affected.

In a province where such a large quantity of wheat is grown like the Punjab the preservation of the wheat which is kept for seed is a serious problem and experiments were started to see whether the use of naphthalene could be applied to wheat in the same way in which it has been applied to maize.

The first point was to determine whether the germination capacity of the wheat was affected in any way by the naphthalene.

In the case of the maize the proportion of naphthalene used was half a seer (1 lb.) per twenty-five maunds (2,000 pounds) or 0.05%. In the experiments with the wheat varying percentages were used. The wheat used was first fumigated with carbon bi-sulphide to ensure that no grain would be spoiled by insect attack and then divided into lots of 300 grams each and these were placed in glass stoppered bottles with the following quantities of naphthalene:—Nil (to act as a control); 2.5 grams; 5 grams; 10 grams; 15 grams; and 20 grams being 0.8 per cent.; 1.6 per cent.; 3.3 per cent.; 5 per cent.; and 6.6 per cent. The experiment was started on 16th December 1912 and on the 17th of each subsequent month until December 1913, 200 grains of wheat were taken from each and placed in a dish upon damp blotting paper to determine the percentage of germination. The results obtained are given in Table XXXVII.

¹ Grove, A. J. Some Experiments with Maize stored in bins. *Agricultural Journal of India*, Vol. IX, pp. 92—98, 1914.

TABLE XXXVII.

Quantity of naphthalene to 300 grains of wheat.	Number of wheat grains which germinated out of 200.											
	January	February	March	April	May	June	July	August	September	October	November	December
Nil ...	175	173	184	176	183	177	180	191	178	181	180	187
2.5 grams	181	183	167	176	172	168	161	162	173	152	134	175
5 ..	178	176	180	175	171	162	168	172	172	156	126	168
10 ..	181	184	170	166	140	161	166	172	167	154	131	160
15 ..	177	164	172	176	133	167	170	175	168	149	123	174
20 ..	180	182	173	168	144	162	168	176	171	175	122	171

These figures show that for the first nine months, that is, from January to September, there is no falling off in the percentage germination that would not be included in the errors of the experiment, and curiously enough the figures obtained in December were higher than those obtained in October and November, and compare very favourably with those of the earlier months. The explanation of this is that in October and November the laboratory temperature was so much lower than in the latter months that the naphthalene did not evaporate so easily from the grains, and the vapour accumulating in the germinating dishes (a distinct smell of naphthalene was observed on several occasions in the dishes), the germinating grains were injured. In December 1913 therefore the grains before being placed in the dishes were exposed to the sun for a period of six hours so that any naphthalene present might evaporate and the results obtained are therefore proportionally higher. In December 1914 that is after the wheat had been with the naphthalene for two years, a test in the field was made. 200 grains from each bottle, after exposure in the sun for several hours, were sown. Unfortunately owing to a canal closure the germinating wheat could not be irrigated by flow irrigation and the hand irrigation resorted to proved unsatisfactory and the germination on the whole was not good, but the conditions were the same for each lot of grain; the results obtained were as follows:—

Quantity of naphthalene...	nil	2.5 gm.	5 gm.	10 gm.	15 gm	20 gm.
No. of grains germinated.	36	16	28	24	25	21

From these it will be seen that even after two years the naphthalene has not had much effect upon the germinative capacity of the wheat.

Mr. H. Southern, Deputy Director of Agriculture at Gurdaspur, used naphthalene in this manner in storing his seed wheat at the Gurdaspur farm, 267 maunds (190½ cwt.) were stored in three large iron bins on 9th June 1914. On 11th August the writer made an examination of these bins and found no insect attack although there were a large number of insects (*C. oryzae* chiefly) in the storehouse, in which the bins were situated. Some other wheat which had been placed in bags on the floor of the storehouse had become badly infected.

This shows that either the wheat was infected when it was stored or else became infected after storing, the latter being the most probable. It is therefore interesting to note that the wheat in the bins had remained free from insects while the wheat in the bags was infected. The cases are not quite parallel as the bins may have been instrumental in preventing the access of the insects whereas the gunny bags would not afford such protection. The method is again being tested this year.

Samples of bread made from wheat which had been stored with naphthalene :—

Since the seed wheat may be stored in the same chambers as wheat which will be sold for food, and because of the difficulty of differentiating between them in the village it was thought advisable to test the wheat after such treatment to see if sufficient naphthalene remained in the grain to flavour the flour or bread made from it. For this purpose samples of wheat treated with naphthalene were first exposed to sunlight to volatilize the naphthalene. The wheat was then reduced to a coarse flour and made into bread.

The following table gives the result of the test :—

TABLE XXXVIII.

Samples of bread made from wheat first stored with naphthalene, and afterwards exposed to sunlight before grinding :—

SAMPLE	DESCRIPTION OF THE BREAD
A. (Pusa) 10-5-1915	No smell of naphthalene.
B. „ 10-5-1915	Slight smell of naphthalene.
C. „ 10-5-1915	Strong smell of naphthalene.
D. „ 10-5-1915	Slight smell of naphthalene.
E. „ 10-5-1915	Strong smell of naphthalene.
F. „ 10-5-1915	Slight smell of naphthalene.
(Gurdaspur) (14) 10-5-1915	Slight smell of naphthalene.
(Pusa) (12) (Gurdaspur) 10-5-1915	Slight smell of naphthalene.

It is clear from this experiment that though we may preserve wheat for seed purposes with this substance, naphthalene cannot be used for wheat which may be sold for food, owing to the objectionable taste and odour it imparts to the bread.

2. *Mechanical Treatment.*

Wheat which has been thoroughly cleaned will be less likely to suffer damage than wheat which is stored without cleaning, for the mere process of sifting will remove a large number of insects which are outside the grain and thus reduce in magnitude the factors causing damage. Moreover the removal of the dust and broken grains will reduce the available food supply for such insects as *T. castaneum*, *C. oryzae* and *L. pusillus* which have been shown to live in the detritus and not on the entire grain. It will also reduce to some extent the number of *A. undulatus* and *R. dominica* larvæ, as it will limit their supply of broken food material and so restrict their development and ability to attack whole grains.

The mechanical cleaning of wheat is practised in the villages by the Indian shopkeeper. Practical experience has taught him that when his grain gets weevilled, it restricts the damage if he sieves out the weevils and dust, and it is therefore a common sight in the Punjab villages to see this thrifty class dealing with the problem in a manner which scientific enquiry has proved to be the best and most efficient method.

The large wheat exporting firms, too, are fully alive to the advantages to be derived from cleaning wheat before export. Though they might not prefer to have the wheat delivered to them in a clean and undamaged condition as the cleaning process is a profitable part of their business, still as one of the managing directors of a large exporting firm said to one of us in discussing the possibilities of introducing elevators into the Punjab "If you can limit the damage caused by weevils, the failure of elevators to establish themselves will be rendered more remote, more, they will probably be a success." As we have already noted in Chapter I, the actual amount of damage caused is not known. Hooper's methods of estimating the damage, mentioned in Noël Paton's *Indian Wheat and Grain Elevators*, are no doubt picturesque, but they are laboratory methods and can only give us the amount of damage under the most favourable conditions for the weevil. The actual damage is much less than Hooper's estimates and the trade figure of from 1 to 5 per cent. is much more likely to be correct since the weevils like most insects have many enemies and very rarely get the chance of doing all the damage they are capable of.

We have already shown in Chapter II the impossibility of using inflammable or poisonous gases for a large granary in this country owing to the prohibitive insurance rates which would certainly be levied, and our experiments in this memoir have shown too, the impossibility of using inert gases

as asphyxiating media, on account of the ability of the insects to protect themselves by restricted respiration.

Drying the grain we have shown in Chapters I and V to be ineffectual, as some of the insects exist better under dry than under moist conditions. *A. undulatus* and others (*R. dominica*) seem to be indifferent, and to flourish equally well in dry or moist grain. In the light of this knowledge the inclusion of a drying plant in an Indian wheat elevator seems an unnecessary expense. If included it will only be of use to deal with wheat which has suffered from exposure to rain, a comparatively rare occurrence in the Punjab.

Chemical deterrents, too, seem to present difficulties in grain which will afterwards be used for food.

We are of the opinion therefore that the only solution to the problem will be found in a mechanical separation of the insects causing the damage.

Conditions which have to be complied with in order to render mechanical treatment satisfactory.

We have shown in Chapter I that damage resulting from the three principal organisms *A. undulatus*, *C. oryzae* and *R. dominica* is caused by the larvæ of the first and the adults of the two latter. The larvæ of *A. undulatus* start to feed almost as soon as hatched. We must therefore remove them when in a young state, or better still remove their eggs if this is possible. The adult insects of *R. dominica* and *C. oryzae* offer no great difficulty since they can be readily sifted out. The chief difficulty seems to be presented by *A. undulatus* and the damaged grains in which weevils have hidden themselves. These grains are uniform with those of unattacked wheat and cannot be separated by sieves. We therefore turned to a mechanical method of treatment which will combine the advantage of sifting with those of a density separation. The principle on which the latter will depend will be the "floating out" of any substances which are of less density than entire or undamaged wheat. Air blasts have been used for cleaning wheat from time immemorial, the separation of the wheat from the chaff by winnowing is certainly the oldest of these methods and is still practised by the Indian peasant in very much the same manner as it must have been by his forefathers thousands of years ago. Various refinements of this method have been introduced into the machinery used for threshing and cleaning wheat, but in all of these machines that we have been able to inspect here in India sieves and shakers appear to form a necessary part of the plant. Now sieves will only operate effectively in removing impurities which are either larger or smaller than the average sized grain. By these means we can certainly clean out stones, foreign seeds of a different size,

or weevils and the detritus which result from their activity. But sieves will not remove grain which has been pierced and partially consumed if the shell is still left almost entire, nor will they remove the weevils contained in such partially hollowed grain. Such impurities not only constitute a direct loss on the entire stock, but may, if the wheat is again stored after sieving, be the starting point for fresh damage after the insects contained therein begin to breed. These grains will be lighter than undamaged wheat in a more or less marked degree according to the amount of endosperm which has been eaten, and will be moved by a current of air more easily than will undamaged grain. The size of the grains will not affect the distance they can be moved by a blast of air provided the density of the contents of the grain are fairly uniform. For though one grain may weigh less than another it will also be smaller and will present a proportionally smaller surface to the action of the air blast. If the $\left(\frac{\text{surface area}}{\text{weight of the grain}}\right)$ remains constant, the effect of the air blast will be fairly uniform, but if the denominator grows less, the effect of the blast will be to move the grain further, or to put it in another way it will require a less powerful blast to "float" the grain.

Experiment.—A mixture of damaged, undamaged wheat, weevils, and their detritus, was allowed to flow from a large glass funnel on to a smooth board sloped at an angle of about 30° (see Fig. 11). The stream of grains,

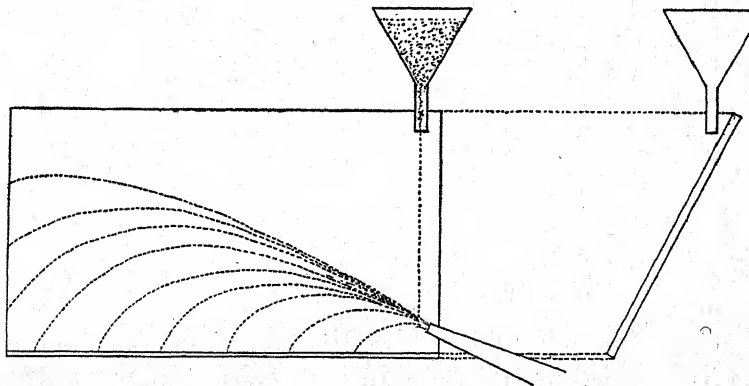


Fig. 11.

as it flows down the board, is struck laterally by a blast of air. The lightest portion of the mixture, the dust, detritus, and weevils, were deflected to the greatest degree from the original line of movement of the grain, and the undamaged grain the least deflected. Between these two extremes we find

mixtures varying from mere empty shells and light matter on the one side to slightly damaged grain on the other. This experiment proved the truth of our hypothesis in a rough manner, but this method is not directly capable of practical application, because the flow of the grain is not sufficiently uniform in character to allow of a uniform velocity in the grain before it is struck by the air blast. After a series of experiments we hit on the design, shown in Fig. 12. This separator consists of a tube (constructed in the experiments

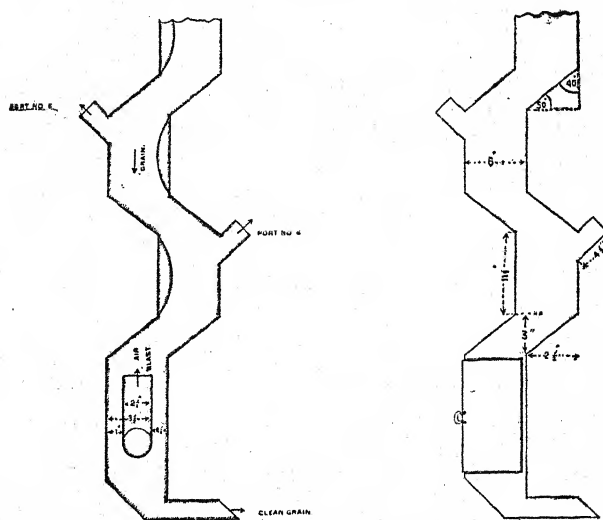


Fig. 12.

of thin sheet iron) with a number of bends, each bend making an angle of 40° with the perpendicular, the object of which is to help neutralize the increasing momentum of the falling grain due to gravitational acceleration. With a tube of sufficient length divided into a sufficient number of steps, we can, in this way, obtain a falling grain of uniform velocity, instead of increasing velocity. If now this grain meets a current of air flowing up the tube, we can by increasing the velocity of the latter ultimately reach a point when its momentum is equal to the momentum of the falling grain. At this point the grain will "float" if we go beyond this, and increase the velocity of the air blast, the grain will be driven back up the tube.

The density of air at 30°C . (a fair average temperature for the tropics) is 0.001165 (water=1) and the density of wheat is from 1.353 to 1.390, see Table XXXIX.

TABLE XXXIX.

Specific gravity of wheat, from the Lyallpur market, compared with water at 15.5°C.

Date of analysis	Description of the sample	Date of purchase	Specific gravity compared to water at 15.5°C	REMARKS
10-6-15	Soft	22-2-15	1.360	Average specific gravity for soft wheat is 1.353.
10-6-15	Soft	30-9-14	1.338	
10-6-15	Soft	7-11-14	1.345	
10-6-15	Soft	28-7-14	1.371	
10-6-15	Soft	29-8-14	1.351	
10-6-15	Hard	30-9-14	1.395	Average specific gravity of hard wheat is 1.390.
10-6-15	Hard	23-10-14	1.382	
10-6-15	Hard	7-10-14	1.396	
10-6-15	Hard	2-2-15	1.397	
10-6-15	Hard	1-4-15	1.379	

When the grain starts to fall from the top of the tube we may consider it as a series of particles having no initial velocity; after falling through a height (h) (in the tube this was 11.5") it will have a velocity of:—

$V = \sqrt{2gh}$, less air friction. It now impinges at an angle of (α) degrees (in this case $\alpha = 40^\circ$) on a sloping surface, from this it will rebound at an angle of θ and will then have a velocity of U where:—

$$U = V \sqrt{\sin^2 \alpha - \xi^2 \cos^2 \alpha} - \text{losses by aerial friction.}$$

for:—

$$U \sin \theta = V \sin \alpha$$

and the relative velocity along the common normal after impact is ($-\xi$) times the relative velocity before impact.

{ (ξ) is the coefficient of restitution or elasticity, in the case of wheat and }
 { iron this is not known. }

$$U \cos \theta - 0 = -\xi(-V \cos \alpha - 0)$$

$$\therefore U \cos \theta = \xi V \cos \alpha$$

from which we have

$$U = V \sqrt{\sin^2 \alpha - \xi^2 \cos^2 \alpha}$$

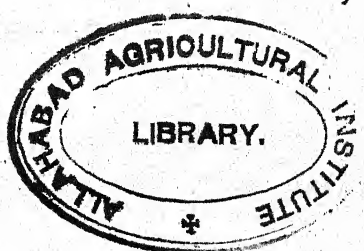
The impulse of the blow will be

$$m V \cos \alpha + m U \cos \alpha$$

$$= m (1 + \xi) V \cos \alpha.$$

This represents loss of energy by impact. If the angle θ is small the grain will start to slide down this sloping surface which makes an angle of (β) with the horizontal and we have:—

V_1 = velocity after sliding over a length (l) with a frictional coefficient of (μ) and initial velocity of U.



We then have

$$V_1 = U + \sqrt{2gl(\sin \beta - \mu \cos \beta)} - \text{losses by aerial friction.}$$

From this point it will fall with increasing velocity over the next straight length of tubing of length h and will strike the next sloping tube with a velocity of V_2 where:

$$V_2^2 = (V_1^2 + 2gh) = \text{all air friction}$$

$$V^2 = \sqrt{V_1^2 + 2gh} - \text{all air friction.}$$

The angle of impact is again the same but the velocity has changed from V_1 to V_2 . The mass remains constant so that the impact of the blow is now

$$m(1+\xi)V_2 \cos \alpha$$

The coefficients of friction between wheat and iron and between wheat and wood are not known but can be easily determined.¹

The above equation gives the momentum M of the mass (m) of moving grain at any point (p) in the tube. This is

$$M_p = mV_p$$

The air moving up the tube is made to leave the nozzle which is fairly wide, with such velocity that it is able to float out grain having a density less than 1.35 and a velocity of V_p opposite the bottom part. It must therefore have a momentum equal to mV_p in the above equation. Making volume unity, i.e., $(1 \text{ cm})^3$, m will be equal to 1.35 (volume \times density), so that

$$M_p = 1.35V_p$$

At this point the momentum of the air will be

$$V_a m = .001165 V_a$$

That is when equilibrium is established between the uprushing air and the falling grain at the point p the grain will have a velocity of

$$V_a = \frac{1.35V_p}{.001165}$$

In calculating V_a we must make allowances for the expansion of the air from the nozzle to the grain tube (in our experiments the cross sectional area of the grain tube was 36 sq. in., while that of the nozzle was 7.86 sq. in.; which mean that the velocity of the air before leaving the nozzle was $\frac{36}{7.8}$ times greater than in the outer grain tube).

Data regarding μ and ξ for wheat, wood, and iron will be available in a subsequent publication.

This friction coefficient is measured by the natural tangent of the angle of slope when the grain just starts to slip. Between wheat and cement it is 0.41667 or an angle of rather more than 22° ; between wheat and wood or iron it will be less than this.

Now the greatest resistance the wheat will experience in the lower part of the tube will be from friction with the rising air which will not only float out the lighter material during its passage through the tube but will in addition tend to reduce the velocity of all the falling grain to a smaller and smaller degree as the velocity of the air is reduced by losses from the port holes in its passage up the tube.

In our experiment the air blast was derived from a Root's blower, and could not be varied, we therefore altered the design of the tube, *i.e.*, altered the angle of the bends, and the distance between them, until the dimensions given in the diagram were arrived at, when the grain issuing at the bottom was found to be clean and free from damaged grain or insects.

Immediately below each bend of the tube there is an egress port. At each of these a portion of the uprushing current of air escapes carrying with it such matter as is light enough to "float" in it. As we proceed up the tube the amount of air escaping at these ports will become less and less. The mechanical effect of this is, that at the top of the tube the lighter materials, insects, dust, and detritus are removed. As it travels down the tube it meets a stronger and stronger current of air and the heavier damaged materials are blown out; first dust, then shells, and afterwards the more or less damaged grain.

Over each of these ports a muslin bag was fixed to collect the products blown out, and the following table gives the separation achieved on 10.76 kilograms of damaged grain containing dust, weevils, etc. The numbers of the bags are from the top downwards:—

TABLE XL.

Showing the cleaning effect of the grain separator described in the text.

					Quantity of material collected
Port hole 1	...	...	...	64 grams	0.59%
Port hole 2	..	...	...	102 "	0.95%
Port hole 3	...	...	...	46 "	0.42%
Port hole 4	...	...	...	72 "	0.67%
Port hole 5	...	...	...	89 "	0.82%
Port hole 6	...	...	...	87 "	0.81%
Port hole 7 (bottom) below the air inlet	..	...	...	10300 "	95.73%
				Total	99.99%

In Table XL, the products collected at port holes 1 and 2 were entirely dust and insects; at port hole 3 the empty shells of grain and cast skins of the larvæ; at 4 empty grain shells and some much damaged grain and at 5 and 6 a less damaged grain. The grain issuing at 7 was clean and free from

adult insects—it contained a very small proportion of slightly damaged grain which showed that beetles probably *A. undulatus* had just commenced to attack it. The advantages of a separator of this type are obvious, there are no moving parts to get out of order as in the case of sieves, the air blast can if required be regulated though this will not be necessary in a large installation; it will only be necessary to see that the fans feeding a given number of separators are running at their proper calculated speed. This can be controlled by the mechanic in charge of the machinery. Lastly the entire products of separation can be collected and used. The dust, detritus, weevils from port holes 1, 2 and 3 can be steamed to kill the weevil and then sold as a manure. This material is rich in nitrogen and phosphates as may be seen from the following table:—

TABLE XLI.

Analyses of the dust, shells and damaged wheat extracted from weevilled wheat by the air blast separator.

	Dust, detritus, dead weevils, etc., port holes 1, 2, 3	Shells port hole 4	Damaged grain from port hole 5	Damaged grain from port hole 6
Total Nitrogen ...	4.51	2.69	1.61	1.58
Total phosphates as P ₂ O ₅ ...	1.68	1.43	0.80	0.78
Carbohydrates { Glucose Sucrose	..... Absent	..... Absent	2.15 Absent	1.85 Absent
Starch ...	.....	.....	58.04	61.77
Protein ...	28.18	16.85	10.0	9.8
Germination value ...	Nil	Nil	3.0	46.0

The damaged grains from ports 4 and 5 might be rolled and pressed into cakes and used as a cattle food and that from 6 might find a sale in the bazaar for the preparation of second grade flour. This utilization of the by-products would help to pay off the running costs and the capital outlay on the plant, for as we shall show later the use of wheat cleaning machinery at Karachi has been so profitable there as to complete the purchase of the plant within two years.

The conditions under which mechanical treatment will have to be applied in an Elevator.

In order to render a process of cleaning wheat satisfactory in India, we must, as far as possible, eliminate the necessity for skilled labour and make the method more or less mechanical. It would not do, for example, if we had to employ skilled scientists to supervise the extraction of the weevils

from the stored grain, or to make periodical inspections, though this latter might possibly be arranged for by the Agricultural Department. This point we have kept well in view in the work of which this memoir is a record, and we have as a result of our entomological studies of the life-histories of the principal insects causing damage, been able to arrive at a working scheme which is to all intents mechanical in its application and can be applied by unskilled labour. From the results given in chapter I, it is clear that if we take an infected sample of wheat and clean it by such a mechanical process as described above, there may still be left on the grain after this has undergone the cleaning process, a number of eggs attached to the epidermis of the wheat. In certain months these will develop and pass through their life-history periods more quickly than in others. If we assume that wheat after this preliminary cleaning is always still infected with eggs which will develop later, then, by allowing the wheat to remain a sufficient time in store for the adult insects to emerge and grow but not to reproduce, and then clean the wheat a second time, we shall be able to completely remove all insects causing damage to the grain. If such wheat is stored in chambers constructed, so that there are no cracks or corners in which the insects can lodge, or to which insects can, in the ordinary course of events, gain access, this double treatment of the grain will completely immunise it against weevil attack. On the basis of the above method, we have drawn up the following table showing the time in days which may be allowed to elapse at various periods of the year between the first and second cleaning.

TABLE XLII.

Table for the use in wheat granaries showing the time which may be allowed to elapse between the first cleaning of the grain on entering the granary and the second treatment to remove insects hatched out from eggs which have escaped the action of the cleaner in the first treatment :—

	Period in days, which must elapse between the first and second cleaning	Period in days beyond which the wheat may not remain in the store without a second cleaning
May	10 days	25 days
June	10 "	20 "
July	10 "	20 "
August	10 "	20 "
September	10 "	15 "
October	15 "	30 "
November	25 "	60 "
December	30 "	100 "
January, February and March	30 "	100 "

Example of the application of the table :—

Wheat is received in an elevator and goes into store after cleaning, say in the beginning of June. The collected wheat should be allowed to remain in the store for not less than 10 days and not more than 20 days when it is again passed through the cleaning machinery and afterwards placed in the permanent store bins, where it will keep for an indefinite period (so far as weevils are concerned).

In the construction of wheat granaries in which this method is to be applied, the temporary store bins should be so constructed as to be self emptying—they should have no sharp corners in which insects or dust can lodge, and the bottom of the bin should slope down to a discharging pipe. The permanent store bins should be of the same shape to admit of easy and complete emptying of the bin when this is necessary.

The separators of whatever types used should be situated preferably in the basement where any leakage of weevils, dust or damaged wheat from the pipes conveying them away from the separators may not fall upon and infect grain stored below.

At the end of March 1915 by the courtesy of the director Mr. J. Muller we inspected a wheat cleaning plant belonging to Messrs. Louis Dreyfus at Kiamari, Karachi. This plant was supplied in 1912 by Werner and Co. of Dresden and consists of two parts (a) a barley extracting plant, and (b) a dust and dirt cleaning plant. Of the two the barley extractor is by far the greater, there being eight cylinders for barley extraction and only one for the removal of dirt.

The cost of the plant at Karachi was Rs. 67,185-10-5 to which must be added Rs. 636-7-3 for the electric installation added in 1914. The cost of the buildings was Rs. 21,980-1-9 and the working expenses for 1914 were Rs. 27,862-11-1 during which period 1,82,537 *candies* of wheat were passed through the machinery. The working costs were 2 annas 5 pies per candy (1 candy = 656 lb. or 0.29286 ton). The repairs executed in 1914 amounted to Rs. 1,245-4-3 and were chiefly for new belting and spare parts for the machinery, this is a low figure and would certainly increase as the machinery ages. The firm calculates depreciation at the rate of annas 2. per *candy* reckoning a 7 years' purchase, but, as a matter of fact, the amount of wheat treated was such as to repay the firm the cost of the plant within two years. Mr. Muller considers this plant will remain in use for 15 years so it will be seen how profitable a cleaning plant of this kind is to a large exporting firm. Other interesting information given by Mr. Muller was to the effect

that the barley extractor is not as useful to them as the dirt extracting machinery, and his firm were negotiating for a new plant at the time of the outbreak of war, to consist of 4 batteries of dirt cleaners only, with a calculated output of 60 tons per hour costing about 2 lakhs in all (building and machinery), all machinery in the newly designed plant to be electrically driven.

The plant we inspected has a guaranteed outturn of 30 tons per hour, but in actual practice the figure of 25 tons per hour has never been exceeded. This falling off is attributed to insufficient sieve accommodation. An inspection of the machinery working on weevilled wheat showed the majority of the dust and weevils were removed in the dirt extractor. The design however is not satisfactory and this part of the machinery is at the top of the building and many weevils escape after extraction and find their way into the cleaned wheat; we found a good many specimens of *R. dominica* in the bagged clean wheat. The sieves too are in our opinion a feature of wheat cleaning machinery which should be reduced to the greatest possible extent.

We give below some details of Messrs. Louis Dreyfus' wheat cleaning plant at Kiamari, Karachi:—

Ground covered by building	...	...	...	28.75 x 10.75 metres.
Ground covered by Powerhouse	...	...	...	8.35 x 6 metres.
Height of building	...	...	...	12 metres at the highest point, average height of roof 8.5 metres.

Cost of machinery supplied by Werner and Co., of Dresden in 1912, working in 1913 Rs. 67,185-10-5

N. B.—Of this sum about Rs. 20,000 is debitable to the cost of the 50 H. P. Oil Motor,

Cost of electric installation for lighting only	...	Rs.	636-7-3
Cost of buildin	...	..	21,980-1-9
Working expenses in 1914 on 182,537 candies	...	..	27,862-11-1
<i>i. e.</i> , R. 0/2/5 per candy.			
Cost of repairs	...	..	1245-4-3

The working expense is divided as follows:—

Wages	...	...	...	2 annas per candy
Oil	...	...	...	2½ pies ..
Repairs	...	...	...	1½ pies ..
Electric fittings and upkeep	...	...	...	1 pie ..

Total 2 annas and pies per candy.

For the purpose of wheat elevators in India it would not be necessary to pass the whole of the grain through machinery to clean it from foreign seeds. Such machinery therefore would have to be in proportion to the amount of

grain requiring such treatment. This can be worked out on the new elevator now in course of erection at Lyallpur, and by examining carefully the average quality of the grain passing through any other centre at which it is proposed to erect similar granaries.

But for the purpose of removing dust all Indian grain must pass through a cleaner at least once (until steam threshers and mechanical winnowers have come into more common use). In order to remove weevils and ensure the grain against damage we have shown that it is necessary to pass the wheat through such machinery twice. The size of the plant for cleaning out dust or weevils will therefore have to be commensurate with the capacity of the elevator to allow of a double cleaning of the wheat during the time it is in store, once at entering and once after storing a sufficient time to allow for the incubation of any eggs escaping the first cleaning processes.

LYALLPUR,

July, 1915.

STUDIES IN THE CHEMISTRY AND PHYSIOLOGY
OF THE LEAVES OF THE BETEL-VINE (*PIPER
BETLE*) AND OF THE COMMERCIAL
BLEACHING OF BETEL-
VINE LEAVES.

PART II.

BY

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INTRODUCTION.

IN July 1913 we published in the present series of Memoirs¹ an account of investigations which we had made into certain questions concerned with the growth and utilization of the betel-vine leaf which, as is well known, forms probably the most important garden crop of India and is also one of the most intensive cultures of the country. We then discussed three questions, namely, (1) the occurrence of nitrates in betel-vine leaves and their relationship to the growth of the vine, (2) the sugars, starch, tannin, essential oil, and other normal constituents of the betel-vine leaf, and their relationship to the growth of the vine, and (3) the commercial bleaching of the betel-vine leaf, and the chemical changes by which it is accompanied. We have since carried our investigations on these questions considerably further and have moreover had the opportunity to examine in more detail than has hitherto been done, the nature of the essential oil, which, from the point of view of the commercial value of the leaf, appears to be the most important constituent of the product. The following is an account of the principal results obtained in these directions.

¹ *Memoirs of the Dept. Agric. India, Chem. Series*, vol. III, no. 2 (1913).



I.

THE NORMAL CONSTITUENTS OF THE BETEL-VINE LEAF AND THEIR
RELATIONSHIP TO THE GROWTH OF THE VINE.

The question which led to our study of the variation of the normal constituents of betel-vine leaves at different periods of their growth, and at various times in the day was really that of ascertaining the cause of the use of the leaf for chewing purposes. As we noted in our former memoir, no appreciable quantity of an alkaloid and no active glucoside seem to be present in the leaf. To what extent therefore the quantity of the other constituents differs at various times in the life of the plant, and what relationship each of them bears to the value of the leaf was the problem before us. In continuation of our former work the following normal constituents have been investigated :— (1) the tannin, (2) the sugars, (3) the starch, (4) the ether extract, (5) the essential oil, (6) the acidity, (7) the diastatic activity, (8) the nitrates. The results obtained and previously published¹ indicated that the leaves near the top of the plants contain much more essential oil,² much more diastase, and much more sugars than those which are lower on the vine. The tannin did not vary in this direction; the leaves of full age in the middle of the vine, neither in the young and actively growing part nor in the older leaves near the base of the plants, contained the largest quantity of this constituent. Further, the constituent which seemed to vary most closely with the market value of the leaves was the essential oil. The present paper carries these results considerably further.

The methods of estimation of these constituents were those employed and described in our previous paper.³

We will first consider the variation of the constituents at different parts of the day in the leaves taken from a normal vine, from which the leaves were being plucked for sale. The samples were taken a few days indeed before the annual operation of taking down the vine, coiling it up and burying it, and allowing it to send out the new shoots, which gradually grow and yield the vines of the succeeding year. This time represents the leaves slightly later than at their best from a commercial point of view.

¹ *Loc. cit.*

² It was erroneously concluded in our previous memoir that the results obtained were connected with the age of the leaves; our later results indicate clearly that it is the position on the plant and hence possibly the relation to light that determines the proportions of these constituents.

³ *Loc. cit.*

Under these circumstances leaves were taken from adjacent vines in the same garden. The leaves were quite mature, fully developed, rather dark in colour, slightly brittle, and with their tips slightly dried. They had been on the vine a little longer than is wise to give absolutely the best results on bleaching, but still they were quite sound and satisfactory for this purpose. Samples were taken on three successive days, taking three samples every day—the first in the morning between 7 and 8 A.M., the second in the afternoon between 1 and 1.30 P.M., and the third in the evening between 6 and 7 P.M.

The results obtained in this series, in view of the fact that leaves for sale are generally plucked chiefly in the morning, are very interesting, and are shown in the following table. All figures are calculated as percentages of the dry matter of the leaves, except the acidity, and the diastatic activity.

	Reducing sugars	Non-reducing sugars	Total sugars	Starch	Tannin	Ether extract	Essential oil	Nitrates (as KNO ₃)	* Acidity	† Diastatic activity
	%	%	%	%	%	%	%	%	cc.	grm.
<i>First day.</i>										
Morning leaves	0.68	2.65	3.33	0.62	0.91	13.4	1.23	1.77	8.50	4.70
Midday leaves	0.90	2.39	3.29	0.87	1.18	12.1	1.35	1.52	8.50	10.20
Evening leaves	1.35	2.55	3.91	1.20	1.18	12.7	1.09	1.36	9.00	5.66
<i>Second day.</i>										
Morning leaves	0.71	2.72	3.43	0.70	1.11			1.89	8.50	4.22
Midday leaves	0.81	2.70	3.51	0.67	1.20			1.79	9.00	9.48
Evening leaves	1.20	2.67	3.87	1.10	1.33			1.65	9.50	7.60
<i>Third day.</i>										
Morning leaves	0.76	2.57	3.33	0.80	1.09			1.77	8.00	6.54
Midday leaves	0.62	2.29	2.91	0.83	1.18			1.60	8.90	9.42
Evening leaves	1.27	2.18	3.45	1.24	1.31			1.43	9.40	6.24

* Cubic centimetres of N/10 Caustic Potash required to neutralise ten grammes of dry leaf.

† Maltose produced by ten grammes of dry leaves in 48 hours.

The average of the three days records gives figures as follows :—

		Reducing sugars	Non-reducing sugars	Total sugars	Starch	Tannin	Ether extract	Essential oil	Nitrates	Acidity	Diastatic activity
		%	%	%	%	%	%	%	%	cc.	gm.
Morning leaves	...	0.72	2.65	3.36	0.71	1.04	13.4*	1.23*	1.81	8.33	5.1
Midday leaves	...	0.78	2.39	3.17	0.79	1.10	12.1*	1.35*	1.64	8.80	9.7
Evening leaves	...	1.27	2.47	3.74	1.18	1.27	12.7*	1.09*	1.48	9.30	6.5

* One determination only.

So far, therefore, as leaves in good condition for eating are concerned, the following results with regard to those constituents would seem to hold.

The reducing sugars and the starch are their lowest in the morning while the non-reducing sugars (presumably chiefly cane sugar) are very constant throughout the day. The change during the day follows somewhat the lines which have been shown to hold with other plants.¹ These are interesting, however, as under the conditions of growth of these leaves the sunshine rarely if ever reaches them. The tannin increases in amount during the day, and hence the leaves in the evening are slightly more astringent than in the morning. The variation in the amount of essential oil seems to be somewhat irregular, but from these figures it rises at first, and then declines toward the evening. The nitrates consistently decline in amount during the light hours of the day, while the acidity consistently increases. The diastatic activity varies curiously. It increases towards the middle of the day in each case, and then declines again towards evening—in one case going below the amount found in the early morning.

¹ Brown and Morris [*Journal Chem. Society*, Vol. 63 (1893), page 669], give following figures for *Tropæolum*, the days being bright and sunny.

	1st day.		2nd day.	
	5 A.M.	5 P.M.	9 A.M.	5 P.M.
Starch	... 1.23 %	4.59 %	3.24 %	4.22 %
Non-reducing sugars	... 4.65 %	3.86 %	4.94 %	8.02 %
Reducing sugars	... 5.14 %	5.72 %	6.80 %	5.19 %

If the fact that the leaves are chiefly gathered in the morning is anything more than a matter of convenience, then one would consider that what was required for eating was a leaf with little starch, tannin, nitrates and acidity, but as much essential oil and cane sugar as possible. This is undoubtedly true as regards the essential oil; with regard to the other constituents the matter must remain in doubt.

So far we have dealt with leaves from similar adjacent vines at different times of the day. We have now to turn to a long series of similar determinations at various stages in the growth of similar and adjacent vines. The vines, as we have already described, are all pulled down at a certain season of the year—generally two months before the commencement of the rainy season—and the stems coiled and buried. From these the new vines arise and form the yielding plants for the following year. The experiments were made with leaves derived from such new vines vigorously growing from the stage when they had reached five to six feet high. In taking them the lower three feet of the vine was always left untouched as the leaves from this part are rarely plucked for use.

Between the third and the fifth foot in height of the vine, there were usually six to eight branches, and on every branch there were at least four leaves. Of these the two nearest the main vine are always small in size, and generally more or less misshapen in appearance. They are never used for bleaching and so in all that follows we have kept these separately from the next two. These two others were, of course, younger leaves but all that were taken were sufficiently mature for use. In the last set a third lot of two leaves was fit for use and was taken. In the present series, however, we are in every case dealing with *still* growing leaves, while in those considered above they are slightly over-mature.

In all five sets of samples were taken from vines adjacent to one another in the same gardens, of the same age and conditions of growth. They were taken on dates as follows:—

1st set	...	July 28, 1913.
2nd „	...	July 30, 1913.
3rd „	...	August 14, 1913.
4th „	...	September 5, 1913.
5th „	...	September 25, 1913.

On one day (September 5th) leaves were taken from the main vine at the same level as these branches to compare with the above.

The following results were obtained, considering the constituents in order :—

1. Moisture.

	Morning 7 - 8 A.M.	Noon	Evening 5 - 6 P.M.
	%	%	%

A. Leaves (two) nearest the main vine.

1st set	...	...	83.5	82.5	81.0
2nd „	...	...	84.0	83.0	80.5
3rd „	...	...	83.0	81.0	85.4
4th „	...	...	83.0	82.5	83.0
5th „	...	...	82.0	82.5	83.0

B. Leaves (two) further from the vine.

1st set	...	...	85.0	84.5	86.5
2nd „	...	...	85.5	89.0	86.0
3rd „	...	...	85.5	86.0	85.5
4th „	85.0	86.0	86.0
5th „	86.0	87.3	87.0

C. Leaves (two) furthest from the vine.

5th set	85.5	86.5	84.5
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D. Leaves from the main vine.

4th set	84.5	85.5	86.0
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These figures were all obtained in the rainy season, and are wonderfully constant. On the whole, curiously, the amount of water in the leaves is smallest in the morning, and it also tends to become greater in the later sets of leaves. But the moisture is, nevertheless, very constant indeed.

2. Sugars.

		MORNING 7 - 8 A.M.			NOON			EVENING 5 - 6 P.M.		
		Reducing sugars	Non-reducing sugars	Total sugars	Reducing sugars	Non-reducing sugars	Total sugars	Reducing sugars	Non-reducing sugars	Total sugars
		%	%	%	%	%	%	%	%	%
<i>A. Leaves (two) nearest the main vine.</i>										
1st set	...	1.61	0.24	1.85	1.80	0.20	2.00	2.50	0.50	3.00
2nd "	...	1.47	0.53	2.00	1.76	0.74	2.50	1.92	1.00	2.92
3rd "	...	1.75	0.56	2.31	1.37	0.82	2.19	1.39	0.87	2.26
4th "	...	1.47	0.44	1.95	1.17	0.49	1.66	1.35	0.39	1.74
5th "	...	1.33	0.14	1.47	0.95	0.27	1.22	1.33	0.40	1.73
<i>B. Leaves (two) further from the main vine.</i>										
1st set	...	0.72	0.28	1.05	1.43	0.66	2.09	1.59	0.64	2.23
2nd "	...	1.35	0.40	1.75	1.28	0.72	2.00	1.07	?	?
3rd "	...	1.53	0.59	2.12	1.23	0.82	2.05	1.60	0.84	2.44
4th "	...	1.43	0.32	1.75	1.61	0.65	2.26	1.40	0.92	2.32
5th "	...	1.00	0.14	1.14	1.30	0.19	1.49	1.13	0.30	1.43
<i>C. Leaves (two) furthest from the vine.</i>										
5th set	...	0.83	0.17	1.20	1.33	0.33	1.66	0.80	0.11	0.91
<i>D. Leaves from the main vine.</i>										
4th set	...	1.37	0.48	1.85	1.23	0.42	1.65	1.22	0.92	2.14

The results obtained from leaves at different parts of the day are interesting to compare with those previously given. So far as sets A and B are concerned, which are the only ones used for eating as a rule, the reducing sugars increase from morning to night, the non-reducing sugars do likewise, but in much greater proportion and taking an average of the ten sets of determinations we have the following:—

		Reducing sugars	Non-reducing sugars	Total sugars
		%	%	%
Morning	...	1.37	0.37	1.74
Noon	...	1.39	0.55	1.94
Evening	...	1.53	0.65 ^a	2.18*

*Average of nine determinations only.



The older leaves on the main vine—which we have previously found abnormal in other respects—and the younger leaves at the end of the branch do not seem to follow the same rule, but the results given are from one set of determinations only, and we should hardly care to place too much reliance upon them.

During the ripening of the leaves—which has more importance for our present point of view—the amount of sugars, both reducing and non-reducing, seem to rise to a maximum and then decline. Taking the average of the morning, noon, and evening determinations we have figures as follows. We have added an average figure for the first two sets, as they were only separated by two days.

		Reducing sugars	Non reducing sugars	Total sugars
		%	%	%
<i>A. Leaves (two) nearest the vine.</i>				
1st set	...	1.80	0.31	2.58
2nd "	...	1.72	0.76	2.81
3rd "	...	1.50	0.75	2.25
4th "	...	1.33	0.45	1.78
5th "	...	1.20	0.21	1.47
<i>B. Leaves (two) further from the vine.</i>				
1st set	...	1.25	0.53	1.79
2nd "	...	1.23	0.56	1.87
3rd "	...	1.45	0.5	2.20
4th "	...	1.48	0.63	2.11
5th "	...	1.14	0.21	1.35

The maximum occurs in the older leaves before it takes place in those further along the branches.

3. Starch. The determinations of starch were as follows :—

		Morning	Noon	Evening
		%	%	%
<i>A. Leaves (two) nearest the main vine.</i>				
1st set	...	1.03	1.36	1.47
2nd "	...	1.15	1.47	1.42
3rd "	...	1.31	1.41	2.13
4th "	...	1.90	1.59	2.00
5th "	...	1.57	1.47	1.59
<i>B. Leaves (two) further from the main vine.</i>				
1st set	...	1.25	1.52	1.65
2nd "	...	1.32	1.30	1.32
3rd "	...	1.56	1.58	2.00
4th "	...	1.59	2.04	3.17
5th "	...	1.54	1.84	2.16
<i>C. Leaves (two) furthest from the main vine.</i>				
5th set	...	1.45	1.80	2.08
<i>D. Leaves on the main vine.</i>				
4th set	...	1.60	2.28	2.08

The results in this case seem very clear. The starch increases consistently toward evening, as would be expected. The increase is not nearly so great as has been found in many cases in plants growing in the sun during the greater part of the day. In such cases Brown and Morris¹ found with *Tropeolum* that the starch increased from 1.23 to 4.59 per cent., and from 3.22 to 4.22 per cent. on two different days for the day as a whole. On the average we have increase as follows :—

	Leaves (two) nearest the vine	Leaves (two) further from the vine
Morning ...	% 1.49	% 1.45
Noon ...	1.46	1.66
Evening ...	1.72	2.06

The starch in these leaves too tends to increase as the leaves get older, but again this probably works up to a limit, and then tends to decline again. The figures though not entirely clear, seem to indicate this, and the small quantity of starch in the much more mature leaves referred to on pages 283 and 4 would seem to justify this contention. If so, taken with the fact that for eating purposes, starch-containing leaves seem objectionable, it would seem one of the factors which prevent young leaves being used for eating as a rule if others are obtainable.

4. Tannin. The figures for tannin are as follows :—

	Morning	Noon	Evening
	%	%	%
A. Leaves (two) nearest the main vine.			
1st set ...	1.17	1.31	1.30
2nd „ ...	0.91	1.04	1.01
3rd „ ...	1.44	1.17	1.43
4th „ ...	1.96	2.06	2.35
5th „ ...	1.56	1.43	1.31
B. Leaves (two) further from the main vine.			
1st set ...	1.67	1.43	1.44
2nd „ ...	1.31	1.17	1.21
3rd „ ...	1.62	1.56	1.70
4th „ ...	1.82	1.69	2.05
5th „ ...	1.95	1.57	1.41
C. Leaves (two) furthest from the main vine.			
5th set ...	2.03	1.82	1.50
D. Leaves on the main vine.			
4th set ...	2.72	1.96	2.21

¹ *Journal Chem. Society*, Vol. 63 (1893), page 669.

Thus the variations in the amount of tannin during the day, and during the growth seem very great, and it is not at all easy to draw general conclusions. On the whole it is not clear that there is any variation in these actively growing leaves which is directly attributable to the period of the day, either in the leaves nearest the main vine or in those further away. The average of the figures above are as follows :—

					Leaves (two) nearest the vine	Leaves (two) further from the vine
					%	%
Morning	..	..	..	..	1.41	1.67
Noon	..	..	..	..	1.40	1.48
Evening	..	..	..	..	1.48	1.57

In the youngest leaves there seems a slight reduction in the evening but that seems the only conclusion we can make.

There does not, moreover, seem to be any decided tendency to increase in the amount of tannin in leaves occupying similar positions in the vine as the young leaves get older ; if anything there are signs of a rise as the leaves mature followed by a decline.

					Leaves (two) nearest the vine	Leaves (two) further from the vine
					%	%
1st set	..	..	..	..	1.26	1.51
2nd	..	..	..	..	0.99	1.23
3rd	..	..	..	..	1.35	1.63
4th	..	..	..	..	2.12	1.86
5th	..	..	..	..	1.43	1.65

These figures rather tend to confirm the previous conclusion that as the leaves get more suitable for eating the amount of tannin tends to decline a little. The difference is not, however, very great.

5. Ether extract and Essential oil. Although the total ether extract has really no special meaning, being a miscellaneous collection of materials

extracted from the leaf, we report the figures with the very important determination of the essential oil:—

		MORNING 7—8 A.M.		NOON		EVENING 5—6 P.M.	
		Ether extract	Essential oil	Ether extract	Essential oil	Ether extract	Essential oil
		%	%	%	%	%	%
A. Leaves (two) nearest the main vine.							
1st set ..	..	6.2	0.7	4.6	0.6	5.8	0.7
2nd „ ..	..	8.6	1.4	6.6	1.4	7.6	1.2
3rd „ ..	..	7.3	2.0	7.2	1.4	7.5	1.9
4th „ ..	..	7.3	1.9	7.9	2.2	8.5	1.5
5th „ ..	..	8.4	3.7	8.5	2.5	8.8	2.9
B. Leaves (two) further from the main vine.							
1st set ..	..	5.5	0.6	6.0	0.6	5.9	0.7
2nd „ ..	..	6.4	1.5	6.5	1.5	6.4	1.8
3rd „ ..	..	6.3	1.5	6.4	2.0	7.7	2.3
4th „ ..	..	6.4	2.5	7.3	2.4	6.8	2.3
5th „ ..	..	8.3	4.3	8.8	2.7	8.9	4.9
C. Leaves (two) furthest from the main vine.							
5th set ..	..	6.0	1.4	5.4	1.6	5.8	2.0
D. Leaves from the main vine.							
4th set ..	..	5.7	1.6	6.8	1.9	7.4	2.0

We shall not further consider the total ether extract, but the essential oil presents some interesting problems.

(a) Variation of essential oil during the day.

			Leaves nearest vine	Leaves further from vine	Leaves furthest from vine	Leaves on main vine
			%	%	(one set only) %	(one set only) %
Morning	..	..	1.9	2.1	1.4	1.6
Noon	..	..	1.6	1.8	1.6	1.9
Evening	..	..	1.6	2.4	2.0	2.0

The variation appears irregular and not clearly a direct consequence of the time of day.

(b) Variation of essential oil of similar leaves during development.

			Leaves nearest vine	Leaves further from vine
			%	%
1st and 2nd sets (average)	..	..	1.0	1.1
3rd set	..	..	1.8	1.9
4th „	..	..	1.9	2.4
5th „	..	..	3.0	4.0

The amount of essential oil increases in both sets, to a very considerable extent. The increase is not a function of the maturity alone, or else those nearest the vine would tend to contain the most, but the position on the branch is effective to some extent. It must not be forgotten that the leaves nearest the vine are not preferred for eating and not used at all for bleaching.

(c) *Variation of essential oil due to position on vine.*

			Leaves nearest vine	Leaves further from vine	Leaves furthest from vine	Leaves on main vine
			%	%	%	%
4th set	..	..	1.9	2.4	..	1.8
5th "	..	..	3.0	4.0	1.7	..

The youngest leaves, hence, at the same time appear to be poorer in essential oil than the others. The constituent quickly increases, however, and a maximum would appear to be reached beyond which it declines. At least this is true unless the first two leaves on the branch are to be considered as quite abnormal.

6. Nitrates. The figures given are calculated as Potassium Nitrate in the dry matter.

			Morning 7—8 A.M.	Noon	Evening 5—6 P.M.
<i>A. Leaves (two) nearest the main vine.</i>					
1st set	..	..	1.4	1.5	2.6
2nd "	..	..	1.5	1.7	1.3
3rd "	..	..	0.6*	1.2	1.4
4th "	..	..	1.1	1.4	1.4
5th "	..	..	1.1	2.5	1.4
<i>B. Leaves (two) further from the main vine.</i>					
1st set	..	..	1.4	1.4	2.5
2nd "	..	..	1.5	1.9	1.5
3rd "	..	..	1.1	1.5	1.8
4th "	..	..	1.3	1.6	1.4
5th "	..	..	1.6	2.4	1.7
<i>C. Leaves (two) furthest from the main vine.</i>					
5th set	..	..	1.5	2.1	1.9
<i>D. Leaves from the main vine.</i>					
4th set	..	..	1.3	1.3	0.9

* This figure seems abnormal, and has been excluded from the averages.

Let us consider the variation of this very interesting constituent during the day, during development, and as due to the position of the leaf on the vine.

(a) *Variation of nitrates during the day.*

			Leaves nearest vine	Leaves further from vine	Leaves furthest from vine	Leaves on main vine
			%	%	(One set only) %	(One set only) %
Morning	..	..	1.3	1.4	1.5	1.3
Noon	..	..	1.7	1.8	2.1	1.3
Evening	..	..	1.6	1.8	1.9	0.9

The amount of nitrates, except in the leaves on the main vine, seems to increase to a maximum in the day, and to remain about at this maximum till evening. The third set is an exception, and in both cases in this set the amount increases towards evening.

(b) *Variation of nitrates in similar leaves during development.*

			Leaves nearest vine	Leaves further from vine
			%	%
1st and 2nd sets (average)	..	..	1.7	2.0
3rd set	..	..	1.3	1.5
4th „	..	..	1.3	1.4
5th „	..	..	1.7	1.9

It seems quite clear from this that the variation in the amount of nitrates is not due to the stage of development, but either to the daily variation in the mechanism of absorption or to some other casual and local factor which our experiments do not reveal.

(c) *Variation of nitrates due to position on vine.*

			Leaves nearest vine	Leaves further from vine	Leaves furthest from vine	Leaves on main vine
			%	%	%	%
4th set	..	..	1.3	1.4	..	1.2
5th „	..	..	1.7	1.9	1.8	..

The position of the leaves on the branch seems to have very little effect on the quantity of the nitrate at any time. This is in accordance with our previous conclusions (see previous Memoir *loc. cit.*, page 20).

7. **Acidity.** The figures are reported as cubic centimeters of decinormal caustic potash required to neutralise the solution from 100 grammes of dry leaves.

				Morning 7—8 A.M.	Noon	Evening 5—6 P.M.
A. <i>Leaves (two) nearest the main vine.</i>						
			%		%	%
1st set	..	..	95.8	109.1	86.0	
2nd "	..	..	90.4	94.0	118.6	
3rd "	..	..	108.4	71.6	99.5	
4th "	..	..	126.5	70.3	72.3	
5th "	..	..	126.8	70.3	70.0	
B. <i>Leaves (two) further from the main vine.</i>						
1st set	..	..	129.4	132.5	115.6	
2nd "	..	..	114.6	96.6	116.2	
3rd "	..	..	123.9	110.4	150.0	
4th "	..	..	145.8	93.0	120.9	
5th "	..	..	123.2	75.8	82.7	
C. <i>Leaves (two) furthest from the main vine.</i>						
5th set	..	..	114.6	80.9	106.5	
D. <i>Leaves on the main vine.</i>						
4th set	..	..	130.1	91.2	94.7	

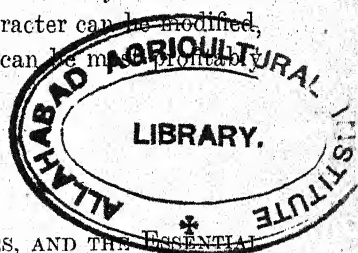
These results seem wholly irregular and do not indicate any constant change in acidity at different times of the day, or at different stages of growth as far as they are included in these series. The acidity, too, is not widely different from that recorded for the slightly over-mature leaves recorded on page 283.

We are now in a position to indicate in some measure what is the composition, in respect to the constituents we have determined, which is desired in leaves for chewing. These, it must be remembered, are usually mature or over-mature leaves, which have actually ceased growing, but have not become brittle, and are most often gathered in the morning. Those which are nearest to the main vine are usually disliked partly because their shape is not so regular, and partly also because they tend to be brittle, and also not to bleach well. Keeping this in mind we may say that, in leaves which are not yet mature, the starch and the non-reducing sugars rise during the day consistently and nitrates appear to do so as well, the reducing sugars (which form two-thirds of the total sugars present) remain fairly constant through the day as does also the tannin and the essential oil. In over-mature leaves, the proportion of reducing sugars is very much smaller, and they are not more than one-third of the total sugar present at any time, and the non-reducing sugars

are fairly constant and are present in by far the greater amount. The starch rises during the day, but slightly only. There is a slight increase in the tannin during the day, while the nitrates decline. The essential oil tends to rise at midday and then fall in the later part of the day.

The leaves, young and growing, and not yet sufficiently mature for eating, contain much reducing sugar, and little cane sugar. The sugar, as a whole, reaches a maximum and then with the maturity of the leaf appears to decline to a practically constant quantity. The same thing happens in the case of starch, and also, curiously enough, in that of tannin. After maturity is reached the tendency for both these is to fall. The essential oil rises to maturity and probably considerably beyond, but falls again when the leaf is considerably over-mature. The nitrates are fairly constant in quantity in similar leaves, throughout the life of the plant.

What is apparently wanted for chewing is a leaf with little starch and reducing sugar, and with an increasing quantity of cane sugar. Changes in the quantity of tannin do not seem material, but excess of this constituent is evidently not required. The value of the leaf is not conditioned by changes in the quantity of nitrates. The vital factor is, as we concluded from our previous paper, the amount of essential oil, which increases very largely as the leaf becomes more suitable for use, and which again declines when the leaf becomes over-mature. It is evident that it is in the study of this constituent, and the manner in which its quantity and character can be modified, that the investigation of the improvement of the leaf can be most profitably pursued.



II.

THE VARIETIES OF BETEL-VINE LEAF, THEIR QUALITIES, AND THE ESSENTIAL OIL IN THEM.

There are few products whose varieties are more widely distinguished by its users than the leaves of the betel-vine. Some, with special qualities, are associated with special places, and we have obtained leaf from a number of these centres, and have distilled the essential oil from most of them. We will now give an account of each of the kinds of leaf we have studied, and afterwards of the differences in their essential oil.

Poona green leaves. This variety is grown generally in the Deccan, and specially in Poona. In Bombay the leaves are much valued, and used. They

are quite soft and sufficiently pungent to be relished both by occasional *pan*-eaters and by those addicted to *pan*-chewing. They bleach very well, and the well bleached leaves are said to be as good as the Ramtek variety.

Ramtek kapuri leaves. These are very soft, and form a good pulp in the mouth. They have a very faint camphor-like smell. Even if eaten to excess they have the reputation of not producing eruptions in the mouth as do many other varieties. They bleach well, and, carefully managed, they will keep well. They are not so good in appearance as Poona leaves, and are large in size. In their own district, near Nagpur, they are the type most valued, as well as in other parts of the Central Provinces and Berar.

Ramtek bangla leaves. These, on the other hand, are not highly valued except by those who are strongly addicted to the habit of *pan*-chewing. They are considerably used by Mahomedans. They are very pungent, and have a very peculiar smell, difficult to describe, when chewed. They do not easily bleach, and are not used for this purpose. They have a local reputation at and near Nagpur.

Baroda bangla leaves. These are very similar in appearance and effect to the last described, and are likewise very pungent and much used by Mahomedans and by the so-called lower classes.

Ranibennur green leaves. Ranibennur is a great *pan*-growing centre in the Bombay Karnatak, and gives two types of leaf, the green and the black. The green leaves are eaten by the higher classes, and scarcely by others or by tobacco chewers. There is little local demand, most being sent to Bombay direct. They are not bleached locally, but in Bombay. They are valued for their softness, easy and good bleaching, good shape, and very good taste.

Ranibennur black leaves. These are used chiefly locally by the so-called lower classes and by those who also chew tobacco leaf. There is no export of these leaves to Bombay. They are very pungent, and are never bleached.

Chikodi green leaves. These leaves, grown in a number of centres in the Belgaum district, are very nearly identical with the Ranibennur green leaves, and very similar to the Poona green leaves.

In quoting these types we have naturally only dealt with those accessible to us. All, except the Ramtek leaves which are famous throughout India, are from the Bombay Presidency, but probably a study of these will give an idea of the nature of the differences in leaves from other places. The attached table is a summary of the qualities of the types we have examined.

Kind of Leaf	Average value per 1,000	Market	"Feel" of Leaves	Colour	Smell	Taste	Shape and Size
Poona green leaves (fresh) ..	Re. 0 12 0 to Rs. 1 4 0	Poona and Bombay.	Soft, not brittle nor tough.	Light green to green.	Nothing peculiar.	Pungent.	Well and regularly marked lines and generally beautiful.
Poona green leaves (bleached) ..	Rs. 2 0 0 to Rs. 3 0 0	Do.	Softer, do.	Yellowish white to yellow.	Do.	Slightly pungent.	Do.
Ramtek Kapuri green leaves (fresh) ..	Re. 1 0 0 to Rs. 1 8 0	Central Provinces and Berar.	Very soft, do.	Light green.	Camphor-like smell when chewed.	Do.	Flat, round, rather big.
Ramtek Kapuri green leaves (bleached) ..	Rs. 1 8 0 to Rs. 3 0 0	Do.	Even softer than the last.	Yellowish white.	Do.	Very slightly pungent.	Do.
Ramtek Bangla leaves ..	Re. 0 12 0 to Rs. 1 4 0	Nagpur and Ramtek.	Not soft, rather brittle and tough.	Dark green.	Very peculiar and strong smell when chewed.	Very pungent.	Small, ovate, rough.
Ranibennur green leaves ..	Re. 0 10 0 to Rs. 1 0 0	Bombay and Locally.	Soft, not brittle nor tough.	Light green.	Nothing peculiar.	Pungent.	Like Poona.
Ranibennur black leaves ..	Re. 0 12 0 to Rs. 1 8 0	Locally.	Not soft, brittle and tough.	Very dark green.	Very pungent smell when chewed.	Very pungent.	Ovate, not big.
Baroda Bangla leaves ..	Re. 0 10 0 to Rs. 1 0 0	Locally.	Not soft, brittle.	Dark green.	Do.	Do.	Round, not very small.
Chikodi green leaves ..	Re. 0 10 0 to Rs. 1 0 0	Bombay and Locally.	Soft, not brittle nor tough.	Light green.	Nothing peculiar.	Fairly pungent	Like Poona.

We may, in fact, class these in several groups, as follows, leaving out the bleached leaves :—

1. (a) Poona green leaves.
(b) Ranibennur green leaves.
(c) Chikodi green leaves.
2. (a) Ramtek *kapuri* green leaves.
3. (a) Ramtek *bangla* green leaves.
(b) Baroda *bangla* green leaves.
4. (a) Ranibennur black leaves.

In our opinion, it is probable that these are really two varieties represented respectively by (1) and (2), and (3) and (4)—the former being green varieties, the latter dark green varieties.

From each of the types quoted in the above table, the essential oil was distilled with steam and the quantity determined, previous to our examination of the properties. The quantities obtained from market samples at the same time of the year are as shown below. Many determinations were made from Poona green and Poona bleached leaves and the figures for these give simply the limits we found.

	Essential oil per cent.
Poona green leaves	1.0 to 2.0
Ranibennur green leaves	1.8
Chikodi green leaves	2.7
Poona bleached leaves	2.0 to 4.0
Ramtek <i>kapuri</i> green leaves	2.0
Ramtek <i>kapuri</i> bleached leaves	3.1
Ramtek <i>bangla</i> green leaves	1.7
Baroda <i>bangla</i> green leaves	3.1
Ranibennur black leaves	3.1

It is, at once, evident from these figures that it is not merely the *quantity* of the essential oil which determines the value of the leaves for chewing, as the least valued of the leaves in some cases contain more essential oil than the most valued. If we except the Chikodi green leaves, none of the more valued light green leaves contain more than two per cent., unless bleached : on the other hand the less valued *bangla* and black leaves contain an average of 2.6 per cent. It was necessary, therefore, not only to consider the quantity of the essential oil but also its composition. This led to a study of the chemistry of *pan* oil.

III.

THE CHEMISTRY OF THE ESSENTIAL OIL OF BETEL-VINE LEAVES.

The work which has hitherto been done on the chemistry of betel-vine essential oil is well summarised in Gildemeister and Hoffmann's work on the Volatile Oils, and we may quote their description in part.

"When and by whom betel oil was first distilled is not known, it is highly probable that the preparation of the oil by Kemp¹ in 1885 was not the first. A superficial examination of Siam betel oil in the laboratory of Schimmel & Co.² in 1887 revealed the presence of a phenol in fraction 250—260°, which seemed to correspond with eugenol. Eykman,³ who in 1888 examined an oil distilled by himself in Java, found no eugenol, but a new phenol which he called chavicol. A second examination in the laboratory of Schimmel & Co. revealed the fact that Siam betel oil contains neither eugenol nor chavicol, but a third phenol, a previously unknown isomer of eugenol, which Bertram and Gildemeister⁴ in 1889 termed betel phenol.

"Betel oil is a light yellow to dark brown liquid of aromatic somewhat creosote-like odour, reminding of tea, and with a pungent taste.

"The specific gravity varies between 0.958 and 1.044; the oil from fresh leaves being lighter both in weight and colour than that distilled from the dried material. The rotatory power was observed on three samples of oil from fresh leaves. Of these two were lævogyrate ($[\alpha]_D$ up to $-1^\circ 45'$) and one dextrogyrate ($[\alpha]_D = +2^\circ 45'$).

"With ferric chloride the alcoholic solution of betel oil produces a greenish to bluish-green colour."

The general result of the work which has been done on the chemistry of the essential oil shows that this oil consists of two groups of constituents, the first class consisting of one or more phenols of the class of eugenol or its isomers and analogues, and the second of a group of sesqui-terpenes of which cadinene was said to be isolated by Bertram and Gildemeister from Siam oil (*loc. cit.*).

Nearly all the work done (except that of Eykman) has been done in Europe on dried leaves—and all except the original preparation of Kemp, on

¹ *Pharmacographica Indica.*

² Bericht von Schimmel & Co., 1887.

³ *Chemiker-Zeitung.* Vol. 12, page 1338.

⁴ *Journal fr. Prakt. Chemie* (II), 39, p. 349.

Java or Siam oils. Our results differ considerably from those published hitherto, and we will simply indicate those which we have obtained.

Separation of Phenols and Non-Phenols in the oil. The phenols and non-phenols were separated by simply shaking the oil with a solution of caustic soda and measuring the loss in volume of the oil. In some cases 5 per cent. and in other cases 15 per cent. caustic soda was used. The percentage of matter dissolved with the latter was higher, while the former seemed to dissolve all the phenolic matter. The figures obtained with the two solutions were as follows with oil from bleached and unbleached leaves:

				5 % Soda Per cent. Phenols	15 % Soda Per cent. Phenols
Sample 1 (Green leaves)	..	..	..	41.0	46.0
Sample 2 (Green leaves)	..	..	..	42.0	49.0
Sample 3 (Bleached leaves)	..	..	..	55.5	64.0
Sample 4 (Bleached leaves)	..	..	..	56.0	68.0

In some cases, for comparison, a direct determination of the non-phenols was also made by extracting the mixed potash and oil repeatedly with ether, and evaporating the solution. This invariably gave a higher percentage of phenols than when the determination was simply made by loss of volume. The relationship between the figures is shown in the following table in five separate lots of leaf:—

					Phenols % (by direct reading of loss in volume)	Phenols % (by ether extrac- tion)
Lot 1 ..	..	..	..	..	70.0	75.3
Lot 2 ..	..	..	..	..	82.0	90.0
Lot 3 ..	..	..	..	..	56.0	73.2
Lot 4 ..	..	..	..	..	45.0	61.2
Lot 5 ..	..	..	..	..	65.0	66.5

In most of our determinations we have simply taken the direct reading of loss in volume, and the exact method of conducting the assay was as follows:—A burette of sixty cubic centimetres capacity calibrated in tenths of a cubic centimetre was almost completely filled with 5 per cent. caustic soda solution, and ten cubic centimetres of the oil added. The burette was stoppered, well shaken, and set aside for twelve to twenty-four hours. Drops of oil which might be adhering to the sides of the burette were then loosened by tapping or rotating the burette, and after the alkaline liquid had become clear the amount of non-phenol oil was read off.

Treated in this way, the various leaves described in the previous section gave figures as follows:—

	Phenols %	Character of the soda solution
Poona green leaves	42.0	Yellow coloured liquid, gradually becoming red.
Ranibennur green leaves	56.0	Dark coloured liquid.
Chikodi green leaves	65.0	Red coloured liquid.
Ramtek <i>kapuri</i> green leaves	70.0	Reddish coloured liquid.
Ramtek <i>bangla</i> green leaves	40.0	Very dark liquid.
Baroda <i>bangla</i> green leaves	45.0	Very dark liquid.
Ranibennur black leaves	39.0	Dark liquid.
Poona bleached leaves	56.0	Red coloured liquid.
Ramtek bleached leaves	82.0	Dark coloured liquid.

From these figures it is obvious that the percentage of phenols in the oil varies very much, and that the higher quality leaf contains the largest quantity of this class of substance, while the lower quality *bangla* or 'black' leaves contain considerably less. Further the effect of bleaching is to increase the percentage of phenols in the oil. Thus we have as follows:—

	Percentage of phenols	Increase by bleaching %
Poona green leaves	42.0	33
Poona bleached leaves	56.0	
Ramtek green leaves	70.0	17
Ramtek bleached leaves	82.0	

Nature of the Phenols in betel-leaf oil. On the question of the nature of the phenols contained in the oil, the information at present is about as contradictory as it possibly will be. As already stated (see page 299), it was first said to be eugenol: then no eugenol was found, and a new phenol named chavicol was obtained from Java oil: then Siam oil was found to contain neither chavicol nor eugenol, but another isomer of eugenol to which the name betel-phenol was given. None of these studies were made with Indian betel-leaf oil.

The three phenols mentioned are said to have the following properties.

Eugenol or allyl guaiacol [C_6H_3 , $C_3H_5(1)$, $OCH_3(4)$, $OH(3)$] is the characteristic phenol of clove oil, and is also contained in cinnamon, sassafras, bay, and a number of other similar essential-oil-yielding plants. It is a yellow liquid, smelling of cloves, with a burning taste, boiling at $252^\circ C.$ at 749 mm. *With ferric chloride in alcoholic solution it gives a blue colour. After shaking with water, the water solution gives no reaction with ferric chloride.* On oxidation it yields vanillin. *It forms a benzoyl compound with benzoyl chloride, melting*

at 69—70°C. and also gives an acetyl compound with acetyl chloride melting at 30—31°C.

Chavicol (Para-allyl-phenol) [C_6H_4 , $C_3H_5(1)$, $OH(4)$], is said to occur in bay oil. It is a colourless liquid boiling at about 237°C. *Its aqueous solution is coloured intensely blue with ferric chloride, but the alcoholic solution only faintly blue.* Its benzoyl ester crystallises in long needles and melts at 72—73°C.¹

Betel phenol. (Chavibetol) is an isomer of eugenol with the formula C_6H_3 , $C_3H_5(1)$, $OCH_3(3)$, $OH(4)$. It is not known from other sources than betel-leaf oil. It is a liquid with a smell much more like betel leaf than eugenol. It boils at 254—255°C. *It gives no colour with ferric chloride in aqueous solution, but an intensely bluish green colour in alcoholic solution. It gives a compound on treatment with benzoyl chloride, melting at 49—50°C. and crystallising in plates.* Acetyl chloride produces a compound boiling at 275—277°C. and melting at 5°C.

These three phenols can evidently be distinguished easily by (1) their reaction with ferric chloride in water and alcohol solutions, (2) by the melting point of their benzoyl compounds, (3) by the boiling point of the phenol. Investigation of the phenols from betel-leaf oil was made in these three directions. Most of the work was done on oil from Poona leaves which had not been dried.

Boiling point of the phenols from betel-leaf oil. The phenols for this inquiry were obtained by the method above described of treating the oil with 5 per cent. caustic soda, and then adding dilute sulphuric acid to the caustic soda solution. The phenols separated easily, and were then used for further experiments.

On heating the phenols thus obtained (which formed a dark red liquid), slight ebullition was noticed when the thermometer in the vapour reached 160°C. but no distillate came over. The thermometer rose then to 251°C.² and the liquid began to distil, and remained constant between 251—253°C. while the greater part of the liquid came over. The distillate was light green in colour.

In a second trial with a new lot of phenols, a small quantity distilled between 98°C. and 108°C. It had a peculiar smell rather like coriander: the

¹ The phenol which gave these figures for the benzoyl compound was prepared by Schimmel & Co., from oil distilled by De Vrij in Java. Its identity with chavicol is probable, but not proved.

² All these determinations of boiling points were made in Poona at an elevation of 1,800 ft. above sea level and are uncorrected.

quantity was very small, and it was chiefly water. No further distillate was obtained below 245°C. Between 245° and 253°C. the liquid distilled fast and the thermometer rose steadily without a break. Only a very small quantity remained at 253°C. when the temperature suddenly rose to 270°C., white fumes were evolved, and decomposition was evidently going on.

In a third trial with still a fresh lot of phenol, a very similar result was obtained at 105°C. Very nearly the whole of the remainder distilled between 246°C. and 251°C. the thermometer remaining constant at the latter figure. The distillate was very light green at first, but became reddish on standing.

This would seem to indicate that no considerable quantity of a substance with the boiling point of chavicol occurs in the Poona *pan* oil.

Reaction of the phenols with ferric chloride. The phenols were only slightly soluble in water. The water used for extraction when filtered gave a slight greenish blue colour with ferric chloride, which became intensely blue on addition of alcohol. This would again indicate that any substance having the properties of chavicol can only exist in traces. As water shaken with eugenol does not give any reaction with ferric chloride, there must be some quantity at least of another phenol—probably betel-phenol.

Investigation of the benzoyl compounds of the phenols. The benzoyl compounds seemed to form the most likely means of ascertaining the nature of the phenols, and hence these were prepared from all the varieties of the oil in our hands.

About five grammes of oil from Poona leaves was taken in the first instance, and treated with 15 per cent. caustic soda solution (20 grammes), and 5 grammes of benzoyl chloride added—the solution being vigorously stirred. An oily precipitate was formed, becoming semi-solid at 10°C. It was then dissolved in hot alcohol, and fractionally crystallised. A small residue was finally obtained from which crystals could not be obtained. The separate fractions crystallised as follows:—

				(1) Original crystals	(2) After recrystallisation
				M. P.	M. P.
1st fraction ..	..	..	..	68°C.	68°C.
2nd ..	..	..	..	67°C.	67°C.
3rd ..	..	..	..	67°C.	67°C.
4th ..	..	..	..	64°C. (yellow)	66°C.
5th ..	..	..	..	67°C.	67°C.
6th ..	..	..	..	67°C.	67°C.
7th ..	..	..	..	51–53°C.	51–53°C.
8th ..	..	..	..	50°C.	50°C.
9th ..	..	..	..	49–50°C.	49–50°C.
10th ..	..	..	..	Uncrystallisable	

All these tests point, therefore, to the fact that while the bulk of the phenols in the essential oil consist of eugenol, there is present with it another phenol having the properties of the betel-phenol previously described. This can be separated by washing the phenols with water, as it is much more soluble in water than the eugenol. This is shown by the following experiment.

10 grammes of the oil were treated with 5 per cent. caustic soda solution (100 c.c.) well shaken, and kept for a day. The non-phenolic matter was then removed, and traces remaining with the alkaline liquid taken away by washing the latter with ether. The residual liquid was treated with dilute sulphuric acid when the phenols separated as a black oily liquid, and the soluble portion was extracted by ether. The percentages obtained thus were as follows :

Non-phenols	29.45 % of the oil.
Total phenols	70.55 % of the oil.

The purified phenols were then shaken with water and filtered. The filtrate gave a slight greenish blue colour with ferric chloride, becoming intensely blue on addition of alcohol. The portion soluble in water was 5.71 per. cent of the original oil.

The separated water-soluble phenol was treated with benzoyl chloride to obtain the benzoyl derivative—and the product crystallised. Crystallisation was not satisfactory, however, either from alcohol, acetic ether or any other liquid tried, even in a freezing mixture. A hard mass was left on evaporation of the solvent which melted at 51—52°C. A very very few crystals separated from alcoholic solution on keeping for a month, which melted at 63—64°C. and which were evidently the benzoyl compound of eugenol. Everything points to this water soluble phenol being a mixture of betel phenol with a small quantity of eugenol, and the two phenols can be partially separated by means of this difference in solubility.

As the determination of the exact nature of the phenols from the betel-leaf oil seemed a matter of importance, and the examination of the benzoyl compounds seemed to afford the most satisfactory means of making it out, a number of other experiments were made as follows :—

(1) *Oil from Poona green leaves.* The phenols and non-phenols were separated by means of 5 per cent. caustic soda solution, the solution treated with sulphuric acid, and the phenols separated from the solution completely by washing with ether. They were then treated in the usual way (*vide supra*) with benzoyl chloride, and the derivative washed with hot water and dissolved in warm alcohol. The solutions of the more easily and of the less easily soluble

portions were kept separately, and allowed to deposit crystals slowly. In both cases big crystals separated after ten days, and gave melting points as follows :—

- (1) derivative from the most easily soluble phenols—M. P. 66—67°C.
- (2) derivative from least easily soluble phenols—M. P. 66°C.

No further crystals were obtained in this case.

(2) *Oil from Poona green leaves.* In this case the phenols and non-phenols were separated by 5 per cent. caustic soda as usual, and the caustic soda solution treated directly with benzoyl chloride. The benzoyl derivative was dissolved in alcohol in two fractions. The solution of the more easily soluble portion gave crystals melting at 66—67°C.; that of the less easily soluble portion gave crystals melting at 64—66°C. On recrystallisation all melted at 66—67°C. The soluble on evaporation gave a residue not containing crystals and which we failed to get to crystallise.

(3) *Oil from Poona bleached leaves.* The experiment was carried out with this oil as in No. 1. All the crystals obtained melted at 66—67°C., but there was a residue in the liquid which we did not succeed in making crystallise.

(4) *Oil from Poona bleached leaves.* This experiment was carried out exactly as in No. 2, but all the crystals obtained melted at 66—67°C. The residual solution could not be made to produce crystals.

(5) *Oil from Poona green leaves.* The phenols were separated as usual with 5 per cent. caustic soda, followed by separation with sulphuric acid. The separated phenols were then repeatedly washed with cold water to get the portion soluble in water, and this water solution was then treated with benzoyl chloride to obtain the benzoyl derivative. This benzoyl derivative crystallised with very great difficulty. On evaporating the alcoholic solution a thick reddish semi-liquid residue was obtained which became hard and solid on rubbing with a glass rod. This hard substance melted at 50—51°C.

The mass was treated with a very small quantity of alcohol insufficient to dissolve the whole. The undissolved residue then melted at 50—52°C.: the solution deposited a very small quantity of crystals melting at 66°C. and a further evaporation gave a residue melting at 50—52°C.

The water soluble phenols in this case consist, therefore, chiefly of a phenol giving a benzoyl derivative melting at 50—52°C. mixed with a small quantity of a phenol whose benzoyl derivative melts at 66°C.

The result of all these experiments seems clear. Two phenols exist in the oil. These, judging by the benzoyl compounds, correspond with eugenol

and betel-phenol. The former is present in by far the largest amount, and is only very slightly soluble in water; the latter (betel-phenol) on the other hand is very fairly soluble in water, and remains in the water-soluble portion mixed with a little eugenol. The portion, from Poona green leaves, soluble in cold water was in one case 5.7 per cent. of the phenols. This will represent slightly more than the proportion of betel-phenol present.

The principal phenol present was always eugenol. In our samples this formed about ninety-five per cent. of the total.

Examination of the non-phenols in betel-leaf oil. The only other materials which have been isolated from betel-leaf oil are terpenes and sesquiterpenes. The position of our knowledge with regard to these is thus stated by Gildemeister and Hoffmann¹.

"Another constituent possibly to be found in all betel oils is cadinene $C_{15}H_{24}$. So far this hydrocarbon has been isolated from the Siam oil only (dihydrochloride M. P. $118^{\circ}C.$). Probably the sesquiterpene (B. P. about $260^{\circ}C.$ Sp. gr. 0.917), found by Eykman in the betel oil from Java is also cadinene. The Java oil from fresh leaves contains a considerable amount of low boiling constituents. Eykman² did not succeed in isolating or identifying a pure terpene of constant boiling point from the fractions between $173-190^{\circ}C.$ Probably several terpenes are present, but apparently no pinene. Fraction $173-175^{\circ}C.$ (Sp. gr. 0.848 at $16^{\circ}C.$; $n_D = -5^{\circ}20'$) yielded neither a solid bromide nor a crystalline hydrochloride. Fractions $190-220^{\circ}C.$ contain substances having a minty odour (menthone or menthol?).

"The oil distilled from dried Siam leaves was devoid of low boiling fractions, only a few drops coming over below $200^{\circ}C.$ "

We have not as yet done more than a preliminary examination of the non-phenolic portions of the essential oil, but the results so far obtained may be recorded.

The non-phenolic portions of the betel-leaf oil were distilled at ordinary pressure and gave fractions (Poona green leaf) as follows:—

No.					%
1	185–200°C.	Chiefly from 195 to 200°C.	..	..	7.4
2	210–230°C.	Chiefly from 220 to 230°C.	..	..	5.3
3	243–245°C.	Chiefly at 244°C.	..	..	6.5
4	247–250°C.	Chiefly at 250°C.	..	..	8.4
5	250–255°C.	Chiefly at 253–254°C.	..	..	29.2
6	256–263°C.	Chiefly at 257°C.	..	..	5.3

¹ *The Volatile Oils*, page 329.

² *Chem. Zeitung*. Volume 12, page 1338.

At 263°C. white fumes commenced to be evolved, and it was evident that decomposition was commencing. The distillation was therefore completed under reduced pressure (350 mm.) and the following further fraction was obtained.

No.					%
7	240-250°C. (at 350 mm. pressure)	..	..	..	11.1
Residue (black in colour)	..	..	..	..	6.8
					<hr/> 100.0

Of these fractions the following notes were made:—

No.

- 1 Colourless liquid with highly fragrant sweet smell.
- 2 Ditto ditto.
- 3 Slightly greenish liquid, with slight fragrant sweet smell.
- 4 Greenish liquid, only very slightly fragrant.
- 5 Liquid, more green than No. 4, with slightly objectionable smell.
- 6 Liquid, more green than No. 5, with very nasty smell.
- 7 Very green liquid.

The distillate No. 6 was redistilled and the green colour was found to be persistent in the distillate.

The specific gravity of each of the fractions was obtained as follows (at 25°C.):

No.					
1	..	..	..	..	0.885
2	..	..	..	..	0.905
3	..	..	..	..	0.944
4	..	..	..	..	0.951
5	..	..	..	..	0.952
6	..	..	..	..	0.952
7	..	..	..	..	0.960

We were unable to detect either cadinene or caryophyllene in any of the above fractions. The examination will however be continued.

Conclusions regarding the essential oil of betel-leaf. The essential oil of betel-leaf consists essentially of two portions, consisting respectively of phenols and of terpene-like bodies. The relative proportion of these varies, and the higher the quality of the leaf, the higher the proportion of phenols in the essential oil. The proportion of phenols in our samples varied from 42 per cent. (Poona) to 70 per cent. (Ramtek *kapuri*) in green leaves of the light green variety, and from 39 per cent. to 45 per cent. in green leaves of the dark green variety. The bleaching of the leaves not only increases very much the total quantity of the essential oil, but also the proportion of the phenols in it. In two cases where bleaching was carried out the increase in the percentage of phenols was from 17 to 33 per cent.

The phenols consist essentially of eugenol in all our cases, mixed with a small percentage of betel phenol. The latter can be largely separated by washing the phenols with water in which it is very much more soluble than eugenol. No sign of any substance having the properties attributed to chavicol has been found in any of our samples.

The non-phenolic portion of the essential oil is a mixture of a number of substances as yet uninvestigated. Over 60 per cent. boils between 240° and 255°C. This has a light green colour, and a somewhat objectionable smell. It is not cadinene or caryophyllene.

IV.

THE COMMERCIAL BLEACHING OF THE BETEL-VINE LEAF.

In our former memoir we discussed the method by which the bleaching of betel-vine leaf is carried on, and found that, as normally conducted, the process results in a very large increase in the amount of essential oil present, in a very considerable increase in the acidity, in a large disappearance of the starch and non-reducing sugars, and in a large decrease in the amount of diastase. We found moreover that oxygen made the process more rapid, and that its absence prevented the change going on. It appeared also that slight acidity was necessary to the process. The problem now before us was to bleach the leaf more rapidly with equal production of essential oil and to obtain a leaf which has the further qualities desired by the consumer.

As usually conducted the process of bleaching is briefly as follows. For further details we must refer the reader to our former memoir (*loc. cit.*).

About fifty to seventy pounds of leaves are packed together in a round basket two to two and a half feet in diameter, and twelve to eighteen inches high, which has been lined with matting. The method of packing is first to cut off the stalks, and then arrange the leaves almost vertically, in layers, forming three or four circular rings of leaves in the basket in each layer. A vertical hole is reserved in the centre, of convenient diameter to allow the hand, when introduced, to reach the bottom layer easily. The whole is then sprinkled with water, and covered with moist gunny cloth, so that it remains in the dark. After three or four days the gunny bag is removed, and the leaves examined. After eight days all are taken out, the bleached leaves and the rotten leaves removed, and the remainder rearranged. All leaves becoming turmeric yellow and not white, and all with red or brown patches are removed. This taking out and picking over is repeated every

five or six days, until practically all the leaves have become bleached, or rotten, or refuse to change colour.

Properly bleached leaves should be very soft, tender, of a sunflower yellow to whitish yellow colour, very bright, clear of any stain as if rotting had commenced, and should become brighter on keeping. A brittle leaf is not liked, and leaves too highly bleached are objected to. When well prepared, bleached leaves are worth three times as much as the original green leaves from which they are obtained.

As already stated, our former work proved that the process was one in which oxidation takes a prominent part, and that slight acidity is necessary to its successful carrying out. The experiments now to be recorded deal with

- (a) the influence of light on the bleaching process,
- (b) the influence of moisture on the bleaching process,
- (c) the influence of varying temperature on the bleaching process.

We have been able to make distinct progress in ascertaining the conditions which lead to rapid and successful bleaching, with the minimum amount of loss on account of the rotting of the leaves.

(a) Influence of Light on the Bleaching Process.

It will be noticed from the above description that in the process in common use, the bleaching of *pan* leaf is carried out in the dark. The basket in which it takes place is always carefully covered, and only at the time at which the picking over of the leaf takes place is the material exposed to the light. The first experiments undertaken, therefore, were to ascertain whether this is a necessary precaution, or whether the presence of light is an indifferent matter.

The first experiment compared the following conditions :—

- (1) Green leaves dipped in water, the excess of water shaken off, and then kept in a nearly saturated atmosphere *exposed to light*.
- (2) Green leaves kept in a saturated atmosphere, airtight, also *exposed to light*.
- (3) Green leaves kept in a nearly saturated atmosphere, in a dark cupboard, and hence only exposed to light occasionally.
- (4) Green leaves kept in a nearly saturated atmosphere, carefully protected from all access of light by means of a dark opaque cloth.

Leaves (eight or nine in each case) kept in these various conditions were watched and examined each day for twenty-four days. The results were clear. Whether judged by the amount of rotting which took place, by the rapidity,

or by the regularity of bleaching, it was evident that light was a distinct disadvantage to the process. The temperature throughout was 24° to 26°C.

In the matter of rotting, after the process was over we had as follows :—

	No. 1 Exposed to light	No. 2 Exposed to light and limited amount of air	No. 3 Kept in the dark	No. 4 Kept in complete darkness
	% None	% 12½	% 78	% 78
Bleached	22	12½	11	None
Partially bleached	45	37½	11	22
Rotting	33	37½	None	None
Will not bleach				

It is evident, therefore, that access of light almost entirely stopped the bleaching process.

Notes made of the process were as follows :—

No. 1 (exposed to light). The proper form of bleaching hardly commenced at all. A certain number of leaves began to turn yellow, and in this sense the process was rapid in the first instance. The yellowness, however, rapidly changed to rotting and eventually most of the leaves were no use either for eating or for further keeping.

No. 2 (exposed to light, with limited amount of air). The proper bleaching in this case also hardly began. The leaves only got yellow spots here and there on the surface. Further bleaching hardly took place except in one case.

No. 3 (kept in the dark). The bleaching was slow, but it went on regularly and continuously. Of the bleached leaves, about half were bleached white and half yellow. The bleached leaves were lustrous, and satisfactory from a consumer's point of view.

No. 4 (kept in complete darkness). The leaves bleached slowly and normally, the majority tending to yellow rather than white, although the number of white-bleached leaves was thirty-three per cent. of the total taken.

A second experiment was now undertaken with a larger number of leaves, generally 64 or 65, weighing in each case one hundred grammes. We compared the following conditions :—

- (1) Bleaching with exposure to light.
- (2) Bleaching in the dark.
- (3) Bleaching exposed to *blue* light.
- (4) Bleaching exposed to *red* light.

The results confirmed the previous experiment, and in addition showed that the exposure to red light was much more fatal to satisfactory bleaching than exposure to blue light. The results tabulated, after twelve days, were as follows :—

	No. (1) Exposed to light	No. (2) Kept in the dark	No. (3) Exposed to blue light	No. (4) Exposed to red light
	%	%	%	%
Total bleached leaves	None	71	60	36
(a) White bleached .. ..	..	46	53	10
(b) Yellow bleached .. ..	..	25	7	26
Half bleached leaves	63	None	None	None
Total rotting leaves	37	29	40	64
(a) Leaves rotting while green ..	37	None	5	34
(b) Leaves rotting after partial bleaching .. ..	..	29	35	30

Thus the maximum amount of rotting took place under the red light, and that under the blue and the white light was about equal. The least took place in the dark. The maximum amount of bleaching took place again when the leaves were kept in the dark. The proportion of the bleached leaves which became white and yellow respectively was

	No. 1 %	No. 2 %	No. 3 %	No. 4 %
White bleached	None	65	89	29
Yellow bleached	None	35	11	71

The yellow bleached leaves are, of course, considered far inferior to those which are white.

(b) Influence of Moisture on the Bleaching Process.

It was noticed in the experiments on the action of light that if the leaves became in the slightest degree dry at the edges or elsewhere, rotting set in almost immediately. Experiments were undertaken, therefore, to ascertain the effect of a perfectly saturated atmosphere or other conditions of moisture on the bleaching process.

The conditions compared were the following :—

1. The leaves were placed in an atmosphere kept nearly saturated by being surrounded with wet gunny cloth, and placed under a bell jar. The gunny cloth did not, however, touch the leaves.

2. The leaves were placed in a similar position to the last, except that the bell jar itself was standing in water. The gunny cloth did not touch the

leaves. The atmosphere may be considered to have been a little more nearly saturated than in the last case.

3. The leaves were placed in a similar position to No. 2, but the wet gunny was re-wetted every morning, and so the conditions were more nearly saturated with moisture than even in the last case.

4. The leaves were placed under similar conditions to No. 3, but the end of the gunny cloth itself was continually dipping in water, and so it was kept continuously re-wetted.

5. The leaves were placed under similar conditions to the last, except that they were surrounded by wet leaves (as they would be in the regular process) which were not included in the experiment.

The leaves kept in No. 1 were, therefore, in the conditions of least saturation, and the saturation was greater in each succeeding case.

The leaves taken in each case weighed one hundred grammes and were from 54 to 60 in number, and the general results were as follows :—

	No. 1	No. 2	No. 3	No. 4	No. 5
	%	%	%	%	%
Total bleached leaves	52	81	70	54	47
(a) White bleached	44	58	64	35	41
(b) Yellow bleached	8	23	6	19	6
Total rotting leaves	48	19	30	46	53
(a) Rotting while green	21	10	3	13	12
(b) Rotting after partial bleaching	27	9	27	33	41

Of the bleached leaves, the percentage bleached white and yellow was as follows :—

	No. 1	No. 2	No. 3	No. 4	No. 5
	%	%	%	%	%
White bleached leaves	84	72	92	65	87
Yellow bleached leaves	16	28	8	35	13

The results thus shown seem to indicate that while enough moisture must be present to ensure that not the slightest drying should take place, more than this is injurious. The best results were obtained (Nos. 2 and 3) when every precaution was taken to ensure that the atmosphere was nearly saturated with water, but when the leaves themselves were not wetted, except at the beginning. If the atmosphere was more nearly saturated than was required to keep the leaves from drying, the amount of rotting rapidly increased, and the number of leaves bleaching properly became very much reduced.

In No. 1, there was a slight sign of the leaves drying at the edges : this has probably caused the very inferior results obtained in that case, and this accounts for the large number of leaves which rotted before bleaching took place.

(c) Influence of Temperature on the Bleaching Process.

It had now become clear that for correct bleaching to occur the leaves must be in the dark, and in an atmosphere nearly enough saturated to prevent the slightest drying. The next point to ascertain was the temperature at which the best results were obtained.

The temperature was obviously an important factor in the process. In the bleaching of *pan* leaves, as commercially carried on, the results are recognised to be much better during some seasons than during others. Thus, for instance, the period from February to May in Poona is the best time for making good bleached leaves, and this corresponds roughly to the hot weather in this part of the country. This is partly due also to the fact that the *junawan* leaves, which give the best results, are more readily obtainable at this period of the year, but the temperature must be recognised to be a factor in the operation.

We, therefore, carried on a number of experiments on this point. In the first of these the process of bleaching was carried on respectively at the room temperature ranging from 26° to 30°C. in an incubator kept at 28° to 31°C. and in an incubator at the higher temperature of 31° to 33°C. The difference between these temperatures is not great, but it is sufficient to have a considerable influence on the result.

The result of the bleaching in each case was as follows, the number of leaves taken being from 62 to 66 :—

			No. 1 26° C. to 30° C.	No. 2 28° C. to 31° C.	No. 3 31° C. to 33° C.
			%	%	%
Total bleached leaves	..	..	47	64	63
(a) White bleached	..	..	41	37	35
(b) Yellow bleached	..	..	6	27	28
Total rotting leaves	..	..	53	36	37
(a) Rotting while green	..	..	12	None	None
(b) Rotting after partial bleaching	..	..	41	36	37

The result at 26° to 30°C. was obviously considerably below the average, but the other two, on similar leaves, were practically equal and were in each case superior to the average, except that the proportion of yellow bleached leaves was higher. But during the process it was noticed that at the higher

temperature the leaves bleached (1) much more quickly, and (2) much more evenly than under ordinary room conditions. The difference in time was considerable. While the bleaching was not completed in No. 1 (the room temperature) until after twelve days, in Nos. 2 and 3 the process was finished after five days. This difference in time probably accounted for the smaller amount of rotting, and also for the rotten leaves rotting after partial bleaching rather than before.

This result was so promising that further experiments were undertaken with larger quantities of leaf. In the first of these we compared :

(1) the bleaching of the leaf under the ordinary room conditions and by the usual method adopted by the *tambolis* (temperature 27°C. to 28°C.)

(2) the bleaching of the leaf at a higher temperature in an incubator (temperature 30° to 35°C.)

(3) the bleaching of the leaf at a much lower temperature, in a box surrounded by ice (temperature 8° to 16°C.).

It may at once be said that no real bleaching took place at the lower temperature (8° to 16°C.). The leaves gradually lost their lustre, becoming dark in colour, and showed signs of decay by the fifth day. This darkening and decaying continued and after a few days further the whole lot had to be thrown away.

In the other two cases the following table shows the general results in the first case for an ordinary bazaar sample of leaves, in the second for a selected sample of *junawan* leaves.

A.—Bazaar leaves (without selection).

Time required for bleaching	No. 1 27°–28° C.	No. 2 30°–35° C.
	17 days	10 days
	%	%
Total bleached leaves	35	84
(a) White bleached	9	68
(b) Yellow bleached	18	14
(c) Partially bleached	8	2
Total rotting leaves	65	16
(a) Rotting while green	21	4
(b) Rotting after partial bleaching	34	12

B.—*Junarwan* leaves.

Time required for bleaching	No. 1 27°–28° C.	No. 2 30°–34° C.
	21 days	9 days
	%	%
Total bleached leaves	74	83
(a) White bleached	30	42
(b) Yellow bleached	35	41
(c) Partly bleached	9	..
Total rotting leaves	26	17
(a) Rotting while green	10	1
(b) Rotting after partial bleaching	16	16

It is evident from these figures, therefore, that the increased temperature has not only increased the speed of the bleaching but it has made it possible to bleach leaves, which are not usually considered fit for this purpose, almost equally well with those which are specially selected for it. Further, even among leaves considered as particularly suitable, a larger percentage of bleached leaves has been obtained at the higher temperature, and less rotting than is normally the case.

The bleached leaves at the higher temperature were of a better colour and more evenly bleached appearance than those conducted by the ordinary process at the ordinary room temperature, and nearly all the leaves were ready on the fifth or sixth day of the process.

It was incidentally noticed during these experiments that leaves whose edges touched metal almost inevitably went rotten, and the same was the case to a less extent if they were in contact with gunny. Loss was minimised if they were in contact with dry plantain leaves, wetted for the occasion.

An attempt was now made to conduct the process at a still higher temperature, namely, 36° to 38°C. but the process totally failed. The leaves began to show signs of drying on the third day, in spite of the saturation of the atmosphere—yellow patches then appeared on all the leaves and these were quickly followed by a general appearance of cooking, and final darkening in colour and decay.

So far the results were obtained with either ordinary leaves or *junarwan* leaves. The younger leaves from the betel vines, notoriously unsuitable for

bleaching by the ordinary process—usually called *navati* leaves—were now taken in order to see how their bleaching would be affected by raising the temperature. The results of an experiment similar to that described for *junawan* leaves were as follows:—

A.—*Ordinary navati leaves.*

Time required for bleaching					No. 1. 24° to 27° C.	No. 2. 29° to 33° C.
					26 days	9 days
Total bleached leaves	..	..	..	..	% 32	% 75
(a) White bleached	..	..	..	..	11	15
(b) Yellow bleached	..	..	..	..	None	60
(c) Partially bleached	..	..	..	..	21	None
Total rotting leaves	..	..	..	..	68	25
(a) Rotting while green	..	..	..	..	45	16
(b) Rotting after partial bleaching	..	..	..	..	23	9

B.—*Selected navati leaves.*

Time required for bleaching					No. 1. 24° to 27° C.	No. 2. 25° to 28° C.	No. 3. 29° to 33° C.
					24 days	18 days	9 days]
Total bleached leaves	..	..	..	..	% 65	% 58	% 73
(a) White bleached	..	..	..	..	7	26	31
(b) Yellow bleached	..	..	..	..	24	32	42
(c) Partially bleached	..	..	..	..	34*	None	None
Total rotting leaves	..	..	..	..	35	42	27
(a) Rotting while green	..	..	..	..	18	15	8
(b) Rotting after partial bleaching	..	..	..	..	17	27	19

* A large number of these leaves showed signs of rotting if further bleaching was attempted. They would not have bleached if kept longer.

The result here is remarkable. By raising the temperature to 29° to 33°C. the *navati* leaves, usually considered as unsuitable for bleaching, have given nearly as good results as the *junawan* leaves so far as total bleaching is concerned, though the proportion of bleaching 'yellow' is greater. Similar results have been obtained in repeated trials, and it may be taken that if the process be conducted at the higher temperature, a much larger range of leaves may be used for the preparation of the bleached product than would otherwise be suitable.

The limits of temperature between which the bleaching process is practicable seem, in fact, fairly well defined. We have never conducted a successful

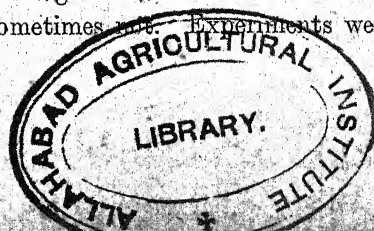
bleaching below 24° to 25°C ., with any kind of leaves, although the leaves do actually bleach slowly as low as 20°C . The upper limit seems to be 33°C . for ordinary or *navati* leaves, and 34° to 35°C . for the best *junawan* leaves. With *navati* (younger) leaves, even 33°C . seems a little too high. As the upper limit is approached, the operation becomes more rapid and regular, but above the point indicated the process will not work, practically, at all.

When the leaves are nearly bleached, it also appeared that the temperature should be lower than in the early stages. If such leaves are suddenly put into a chamber at 32°C ., they begin to turn yellow and then suddenly to start rotting. When such leaves are kept at the ordinary temperature (that is to say, from 25°C . to 26°C .), they remain in good condition without much loss in lustre or colour for a long period.

The actual loss in keeping well-bleached leaves at 25° to 26°C . was tested with forty-five leaves, kept in an atmosphere nearly enough saturated to prevent drying. All were rotted after a month, and the progress of the decay is shown in the following table :—

Days				Number of leaves good	Number of leaves rotting	Percentage of leaves rotting
Beginning	..	..	..	45	..	..
After 15 days	..	..	..	30	15	33.3
After 25 days	..	..	..	25	20	44.4
After 27 days	..	..	..	14	31	68.9
After 29 days	..	..	..	7	38	84.4
After 31 days	..	..	..	None	45	100.0

So far we have only considered the effect of temperature on the bleaching of the leaves as judged by appearance. It has been previously indicated, however, that the process derives its value largely from the fact that, as usually conducted, it is accompanied by an increase in essential oil, and especially in the phenolic portion of the essential oil. We have now to consider whether conducting the process at a temperature higher than that usual will lead to an equal increase in essential oil. That is to say :—Are the change in colour and the increase in essential oil parts of one process,—or are they independent changes going on in the leaf ? In the former case, the change in colour would be all we need aim at : in the latter it might sometimes be an indication of the highest quality of bleaching, and sometimes not. Experiments were undertaken to test this point.



At first a few leaves only were kept under various bleaching conditions, and the essential oil determined in each case from those which bleached in a more or less satisfactory manner. The results were as follows :—

A.—*Bazaar sample of junawan leaves.*

		Essential oil
		Per cent.
Fresh green leaves	.. ..	2.08
Leaves bleached by usual method	.. ..	3.82 (greenish white).
Leaves bleached at 30° to 32° C.	.. ..	2.64 (very thoroughly bleached).
Leaves kept for bleaching below 20° C.	.. ..	1.72 (somewhat yellow).

B.—*Selected sample of junawan leaves.*

		Essential Oil
		Per cent.
Fresh green leaves	.. ..	4.31
Leaves bleached by usual method	.. ..	6.17 (yellowish white).
Leaves bleached at 30° to 32° C.	.. ..	8.42 (white).
Leaves bleached at 32° to 35° C.	.. ..	3.84 (yellow).

It seemed probable, therefore, that the process of bleaching and the production of essential oil were distinct processes, that the production of yellow leaves was not associated with an increase in essential oil while that of white leaves was, and that if the temperature be increased too far, the essential oil does not increase at all.

A larger lot of leaves was taken, under more normal bleaching conditions than could be given in a small sample, and the effect on the essential oils determined.

A.—*Bazaar sample of junawan leaves.*

		Essential Oil
		Per cent.
Fresh green leaves	.. ..	2.15
Leaves bleached by usual method (at 27° to 28° C.)	.. ..	3.14 (greenish white).
Leaves bleached at 30° to 34° C.	.. ..	2.64 (very thoroughly bleached).

B.—*Selected sample of junawan leaves.*

		Essential Oil
		Per cent.
Fresh green leaves	.. ..	4.58
Leaves bleached by usual method (at 27° to 28° C.)	.. ..	5.14 (greenish white).
Leaves bleached at 30° to 34° C.	.. ..	4.51 (very thoroughly bleached).

At a temperature of 30° to 34° C., therefore, while the bleaching was excellent from a point of view of appearance, there did not seem in this experiment to be the same increase in essential oil as was obtained under the more usual conditions. This proves, we think, that the processes of change of colour,

and of increase in essential oil are largely independent—but it is still a question whether the higher temperature causes less production of essential oil, or whether under the very thorough bleaching, usually obtained, it is first formed and afterwards disappears.

That the latter is probably the case was indicated by an experiment with ordinary *navati* leaves, in which the bleaching was not allowed to go so far, and which gave the following results:—

Ordinary navati leaves.

	Essential Oil
	Per cent.
Fresh green leaves	1.36
Leaves bleached by usual method (at 24° to 27° C.) ..	2.83 (yellowish).
Leaves bleached at 29° to 33° C. ..	3.07 (yellowish white).

Here the leaves bleached at the higher temperature are fully as good as those bleached at 24° to 27°C., but with them the process has not been carried so far as in the cases previously given.

The question of the relationship of the change in colour, and the increase in essential oil could, however, only be settled by following, from day to day, the growth of essential oil in a batch of bleaching leaves, both under ordinary conditions and under conditions of higher temperature. This has been done with both ordinary and selected *navati* leaves.

A.—*Ordinary navati leaves.*

(1) Bleached at 27° to 28°C.

	Essential Oil
	Per cent.
Original leaves	2.27 (green).
Leaves four days later	2.67 (greenish).
Leaves six days later	2.70 (greenish yellow).
Leaves eight days later	2.41 (greenish yellow).
Leaves ten days later	2.81 (greenish yellow).
Leaves twelve days later	3.14 (yellowish white).
Leaves fourteen days later	2.47 (yellowish).

(2) Bleached at 29° to 33°C.

	Essential Oil
	Per cent. *
Original leaves	2.27 (green).
Leaves two days later	2.02 (greenish).
Leaves four days later	3.09 (yellowish).
Leaves six days later	2.99 (yellowish white).
Leaves eight days later	1.83 (very thoroughly bleached).

B.—*Selected navati leaves.*

(1) Bleached at 27° to 28°C.

	Essential Oil
	Per cent.
Original leaves	2.01 (green).
Leaves two days later	2.31 (green).
Leaves four days later	2.36 (green).
Leaves six days later	2.44 (greenish).
Leaves eight days later	2.41 (greenish).
Leaves ten days later	2.74 (greenish yellowish).
Leaves twelve days later	2.46 (greenish yellowish).
Leaves fourteen days later	2.52 (greenish yellow).
Leaves sixteen days later	3.16 (greenish yellow).
Leaves eighteen days later (average)	3.40 (yellowish white).
Leaves eighteen days later (best bleached leaves, selected)	5.00 (yellowish white with green tinge).

(2) Bleached at 29° to 33°C.

	Essential Oil
	Per cent.
Original leaves	2.01 (green).
Leaves two days later	2.15 (greenish).
Leaves four days later	2.88 (greenish yellow).
Leaves six days later (average)	3.17 (yellowish white).
Leaves six days later (best bleached leaves, selected)	4.06 (yellowish white with green tinge).
Leaves eight days later	2.00 (very thoroughly bleached).

These figures show in every case that the increase in essential oil is a continuous process, until the leaves reach a yellowish white colour, with a tinge of green. If they are bleached further than this the amount of essential oils rapidly declines again. If this fact be taken into account the bleaching at a higher temperature gives almost, if not quite, as large an increase in essential oil as in the process as usually carried out—but the danger of over-bleaching in this case is considerably greater.

The process and its results, as conducted at a higher temperature, have been shown to some of the *tambolis*, who have highly approved of the resulting leaf, and of the reduced amount of rotting thus obtained. It remains, however, to devise an apparatus in consultation with the *tambolis*, which they can use in practice, in order to yield equally good results, and this will be the next step in bringing the results here indicated into use by the manufacturers of bleached betel vine leaves.

In the meantime, our results seem to prove:

(1) that the bleaching of betel vine leaf can only be carried out in the absence of light. Under white light little or no normal bleaching takes

place. Both red and blue lights are injurious, the former much more so than the latter ;

(2) the atmosphere under which bleaching is conducted must be sufficiently saturated to prevent the slightest drying of the leaves—as drying is always followed by rotting. Greater saturation than is required to keep the leaves from drying leads, however, to increase in the rotting ;

(3) the bleaching process can be carried on much more rapidly and evenly if the temperature be increased to 29° to 33°C. A temperature higher than 35°C. (or less with *navati* leaves) is fatal and yields no bleached leaves—and a temperature lower than 24°C. is equally useless ;

(4) bleaching at a higher temperature (29° to 33°C.) if checked at the proper point, leads to almost as great an increase in essential oil as if the bleaching is done at the ordinary temperature, as is usual—and as it gives less loss from rotting of the leaves, and can be carried on more rapidly, it has very considerable advantages. Nearly the same results can be obtained in six days as require sixteen days by the more usual process ;

(5) if bleaching is carried on beyond the stage when the leaves are yellowish white, the amount of essential oil rapidly declines, and hence the leaves should be removed at this stage. As the rapidity of the process is greater there is more danger of such over-bleaching when it is conducted at a higher temperature as here suggested ;

(6) it only now remains to devise an apparatus which the *tambolis*, who prepare the bleached leaves, can use, and this is now being done.

CONCLUSION.

Such are the results which we have now obtained. We have shown the character of the leaf which is required for chewing, and have found more clearly than ever that it is the quantity, and also the character, of the essential oil which seems most largely to determine the value of any sample of betel-vine leaf for this purpose. This being proved, the way is open for an attempt to discover what modification in the growing conditions will affect the amount and character of the essential oil in the desired direction—and this will be the next line of investigation as regards the cultivation of the vine.

The essential oil itself, however, is not always the same. It consists of a mixture of certain phenols and of certain terpene-like constituents. As far as the phenols are concerned, eugenol is always the chief constituent in Indian oils, mixed with a small quantity of betel phenol. We have never found chavicol in Indian oils. The best essential oil, from a point of view of public

taste, is that which contains as large a proportion of phenols as possible. Those varieties of leaf which gives an essential oil containing much terpene are very pungent, but are looked upon as very coarse. Bleaching not only increases the amount of essential oil in the leaf, but also increases the proportion of phenols in the essential oil. The nature of the terpene-like constituents is still unknown but will be investigated at the first opportunity.

Bleaching of the leaf must be carried out in the dark, and can be most successfully accomplished at a higher temperature than is usual, say between 29° to 33°C . with much less loss, in much shorter time, and with a much more evenly bleached leaf than is usual. If over-bleaching is avoided, the increase in essential oil is nearly equal to that obtained in the ordinary process. The best means for carrying out this improved method in practice is now under investigation.

POONA,

October, 1915.
